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BERYLLIUM IODOMERCURATES

A. V. Slavvo

The first reports of the preparation of double salts of mercuric iodide and the lower iodides of metals go back to the past century. The production of such compounds is mentioned in the papers by Berthemot, Bonsdorf, and Boullay during the first half of the nineteenth century, and later in papers by Duboin, Dobroserdov, Pavlov, Bogorodsky, and others.

The researches of these authors were chiefly directed to the preparation of new compounds, Dobroserdov being the only one to subject the accumulated experimental material to systematic examination.

According to Dobroserdov [1], all the iodomercurates are salts of two complex acids, $H[HgI_3]$ and $H_2[HgI_4]$, known only in solution. Thus, Dobroserdov reduces all the iodomercurates to two types of salts, $Me[HgI_3]$ and $Me_2[HgI_4]$, Me being an ion of a monovalent metal.

Yet, despite the extensive experimental material dealing with the preparation and study of iodomercurates of the metals of Groups I and II of the periodic system, there is no reference in the literature to the iodomercurates of beryllium. This is the motivation for the present research.

In conformity with Dobroserdov's views, our first experiments aimed at the production and isolation of beryllium tri- and tetraiodomercurates. To secure these salts we prepared a solution of beryllium iodide by dissolving metallic beryllium in strong HI, using 1 gram-atom of Be to 2 moles of HI.

A fresh solution of BeI_2 was saturated with enough anhydrous HgI_2 (two samples being employed) to get salts of the following composition: $Be[HgI_3]_2$ and $Be[HgI_4]$.

Our experiment indicated that in preparing beryllium triiodomercurate the theoretically required quantity of HgI_2 dissolved only when the mixture was heated on a water bath. Cooling the solution to room temperature caused the immediate precipitation of much of the dissolved HgI_2. When the solution was kept in a desiccator over conc. H_2SO_4 a little more HgI_2 precipitated as large, well-formed crystals.

In preparing the $Be[HgI_4]$ salt all the theoretically required HgI_2 dissolved completely in the cold. Both solutions were extremely hygroscopic and unstable when diluted with water. Adding one to two drops of water to 3-5 ml of the solution caused the immediate decomposition of the resultant salt and the precipitation of HgI_2.

It was extremely difficult to establish that a complex salt had been formed in the solution, owing to the solution's excessive hygroscopicity and its instability when diluted with water. Of the existent methods, the only usable ones were the analytic, with the further major restriction that only gaseous reagents could be employed to detect the ions making up the salt, inasmuch as they did not produce any change in the solution concentration. Using nothing but gaseous reagents, we managed to establish the presence of only part of the ions comprising the salt. We were unable to precipitate HgS by using H_2S, one of the most sensitive reagents to the mercury ion, which proved that the mercury was part of a complex ion; NH_3 precipitated beryllium hydroxide, indicating the solution contained free beryllium ions. These tests showed that the solution contained beryllium iodomercurate.

The resultant solutions were kept in a desiccator over H_2SO_4 (sp.gr. 1.84) for about 3 months to secure crystals of the salt. As the solutions thickened HgI_2 gradually precipitated and hydrogen iodide was evolved instead of the expected isolation of the crystals of beryllium iodomercurate, as a result of the decomposition of the complex salt:

$$Be[HgI_4] = HgI_2 + BeI_2;$$

$$BeI_2 + HOH = BeOHI + HI.$$

weakening of the depolarizing action of the beryllium ions. The diminution of the field of force of the ions in the outer sphere is caused by the partial extinction of the positive valencies of the beryllium ions, due to the addition of the hydroxyl groups. It must be supposed that the divalent beryllium ion adds a single hydroxyl group and becomes monovalent, in which case its polarizing action should differ but little from the action of other monovalent ions with approximately the same radius.

We had to establish the composition of the complex radical to prove that these assumptions were correct. This problem was solved analytically by precipitating the complex ion and making a complete chemical analysis of the precipitate. Three reagents were chosen for this purpose: $CuSO_4$, $AgNO_3$, and $[Pt(NH_3)_4]Cl_2$, in each of which we could expect a double decomposition reaction to result in the formation of a slightly soluble compound containing the complex ion, by analogy with the complex radical $[HgI_4]^{--}$ [3,4,5].

In view of the decomposition of the salt when water is added, these salts had to be synthesized in the dry state; this was done by comminuting the crystalline salts of the initial products in the appropriate proportions (based on the monovalent and divalent complex radicals $-[HgI_3]^-$ and $[HgI_4]^{--}$) until a homogeneous mass was produced, which became moist as the result of its greedy absorption of atmospheric moisture. In each of the three cases the color of the mass changed markedly during comminution.

During the synthesis of copper iodomercurate the iodine ions were partially oxidized to free iodine, large quantities of which were evolved.

The results of our analyses of the reaction products are listed in Tables 4 and 5. The analysis data on copper iodomercurate in Table 4 enable us to establish the simplest chemical formula: $CuI \times HgI_2 \times H_2O$ or $Cu[HgI_3] \cdot H_2O$ (Table 4).

Percent Analysis of Copper Iodomercurate

TABLE 4

	I	II	III	Mean of 3 determinations
Copper	9.54	9.57	9.69	9.60
Mercury	30.18	30.39	30.36	30.31
Iodine	57.72	57.50	57.34	57.52
Water (by differences)	2.56	2.54	2.61	2.57

TABLE 5

	Per cent found	Per cent calculated from the formula
Copper	9.60	9.59
Mercury	30.31	30.26
Iodine	57.72	57.44
Water (by differences)	2.51	2.71

Percent analysis of tetrammineplatinum iodomercurate (Table 6)

On the basis of the analysis results we have assigned this the simplest chemical formula: $[Pt(NH_3)_4][HgI_3]_2$.

TABLE 6

	I	II	III	Mean of 3 determinations
Mercury	28.34	28.08	28.21	28.21
Platinum	13.54	13.77	13.43	13.58
Iodine	53.27	53.24	53.51	53.34
Water + NH_3 (by differences)	4.85	4.91	4.85	4.87

TABLE 7

	Per cent found	Per cent calculated from the formula
Mercury	28.21	28.14
Platinum	13.58	13.69
Iodine	53.34	53.40
Water + NH_3 (by differences)	4.87	4.76

Percent analysis of silver iodomercurate (Table 8).

The formula $3AgI \cdot 2HgI_2$ or $2Ag[HgI_3] \cdot AgI$ best fits the composition indicated.

The results of analysis lead us to believe that the precipitate of silver iodomercurate consists of two

TABLE 8

	I	II	III	Mean of 3 determinations
Silver.....	20.85	21.43	21.63	21.18
Mercury.....	24.70	23.80	23.53	24.01
Iodine.....	54.45	54.73	54.66	54.62
Water (by differences).....	0.40	0.02	0.18	0.20

TABLE 9

	Per cent found	Per cent calculated from the formula
Silver.....	21.17	20.06
Mercury.....	24.01	24.88
Iodine.....	54.62	55.07
Water (by differences)	0.21	–

TABLE 10

	I	II	Mean of two determinations
AgI (residue after distillation)	45.94	46.20	46.03
HgI_2 (by differences)	54.06	53.80	53.93
Water (by increase in weight of $CaCl_2$).....	None found		–
	Per cent found		Per cent calculated from the formula $2Ag[HgI_3]\cdot AgI$ (%)
Silver iodide.....	46.07		43.66
Mercuric iodide.....	53.93		56.36

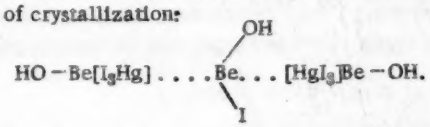
slightly soluble salts, $Ag[HgI_3]$ and AgI, their proportions in the mixture by weight being 2:1.

The foregoing analysis of the silver iodomercurate was paralleled by a simplified analysis of this salt, involving its decomposition into the constituent salts AgI and HgI_2 (this method is founded upon the difference in the volatility of mercuric and silver iodides when heated). The results are given in per cent in Table 10.

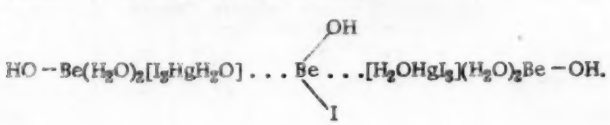
The discrepancy between the experimental figures and those calculated theoretically proved that the resultant compound was a mixture. It may be stated, however, that in spite of this discrepancy the simplified method of analysis also confirms the derived formula for silver iodomercurate: $2Ag[HgI_3]\cdot AgI$.

Thus, in all three cases we were able to isolate the complex ion in the precipitate and to demonstrate its composition analytically as $[HgI_3]^-$.

The results of these analyses are grounds for our proposing the following coordinate formula for basic beryllium iodomercurate, ignoring the water of crystallization:



The following hypothetical distribution of the molecules of crystallization water may be assumed for the crystal hydrate of beryllium iodomercurate:



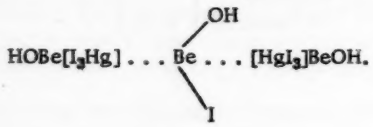
SUMMARY

1. It has been shown that it is impossible to isolate crystal hydrates of beryllium iodomercurate of the following composition: $Me[HgI_4]\cdot xH_2O$ from aqueous solutions, though salts of this composition have been recovered under similar circumstances for all the alkali-earth metals and for magnesium.

In our opinion, the impossibility of isolating the crystal hydrates $Be[HgI_4]\cdot xH_2O$ is due to the high depolarizing effect of the beryllium ion.

2. It is comparatively easy to isolate the crystal hydrate of basic beryllium iodomercurate, which has made it possible to synthesize for the first time the complex salt of basic beryllium iodide and iodomercuric acid $H[HgI_3]$, and to investigate its properties.

3. The coordinate formula of the compound synthesized:



was established by the analytical method.

Hence, introducing hydroxyl groups, which partially extinguish the positive valencies of the beryllium ions, into the beryllium iodomercurate molecule diminishes their field of force, weakens their depolarizing action, and promotes the increased stability of the complex ion.

4. During the establishment of the coordinate formula of the basic beryllium triiodomercurate analytically we have synthesized for the first time the copper, silver, and tetrammineplatinum iodomercurates, with the following formulas: $Cu[HgI_3]\cdot H_2O$; $Ag[HgI_3]$ and $[Pt(NH_3)_4]\cdot[HgI_3]_2$.

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BERYLLIUM CHLOROMERCURATES

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Little research has been done on the halogenated compounds of mercury and beryllium. The data encountered in the literature, dealing with the production of chloro- and bromomercurates of the metals in Group II of the periodic system, are evidence of how little work has been done on this problem.

It is stated in the literature that salts of the following compositions: $BaCl_2 \cdot HgCl_2 \cdot 8H_2O$ [1]; $MgCl_2 \cdot 3HgCl_2 \cdot 6H_2O$ [2,3,4] and $BaCl_2 \cdot HgCl_2 \cdot 2H_2O$ [2], have been secured as crystal hydrates, though the preparation of the last salt has not been confirmed by subsequent investigations.

As for beryllium, Bonsdorff is the only one who asserts that the reaction of concentrated solutions of mercuric chloride and beryllium chloride results in the formation of a salt of the composition: $xBeCl_2 \cdot yHgCl_2$. This formula indicates that the author never made a complete analysis of this compound.

In view of the difficulties we encountered in preparing and isolating the crystal hydrates of normal beryllium iodomercurate, due to the high polarizing effect of the beryllium ions in the outer sphere, it might have been thought that the chloro- and bromomercurates of this metal ought to exhibit a higher stability of the complex radical. The radii of the chlorine and bromine ions are smaller than the radius of the iodine ion, and hence the former's lesser tendency to polarization ought to make the complex radicals of the chloro- and bromomercurates more stable, inasmuch as the influence of the outer sphere – the counterpolarizing action of beryllium – ought to be less in these salts. The ease with which the basic salt of beryllium is isolated is due, as we have seen, to a decrease in the counterpolarizing action of the beryllium ions, resulting from the introduction of hydroxyl groups into the outer sphere.

In the light of these considerations we were greatly interested in preparing the normal and basic chloro- and bromomercurates of beryllium in the crystalline state.

Preparation of Beryllium Chloromercurate

The beryllium chloride required in the synthesis of normal beryllium chloromercurate was prepared by dissolving metallic beryllium in 36% hydrochloric acid, the proportions being 1 gram-atom of Be to 2 moles of HCl. The beryllium dissolved violently, large amounts of heat being evolved. We secured a light-yellow solution of $BeCl_2$, the percentage composition of which is given in Table 1.

TABLE 1

	I	II	III	Mean of 3 determinations
Beryllium	2.99	2.94	2.98	2.97
Chlorine	23.29	23.44	23.44	23.39
Water (by differences) .	73.72	73.62	73.58	73.64

Composition of the $BaCl_2 + 12.4H_2O$ solution. 100 g of solution contained 26.29 g of $BeCl_2$ at 15°. A beryllium chloride solution of this concentration was saturated in the cold with $HgCl_2$, 1 mole of $HgCl_2$ being added per mole of $BeCl_2$. This yielded a straw-yellow solution of slight density. The presence of free beryllium ions in this solution was demonstrated by the use of gaseous ammonia, while the action of hydrogen sulfide proved that it contained no mercury ions. These tests confirmed that a coordination compound – beryllium chloromercurate – had been formed in the solution.

The solution was placed in a desiccator at 14-16° together with sulfuric acid (sp.gr. 1.84) in order to concentrate it. Two months later crystals of the salt appeared on the surface of the solution.

The specific gravity of the mother liquor was d_{15}^{15} 3.16 at the instant of crystallization. The solution was analyzed to determine its beryllium, mercury, and chlorine content. The beryllium was determined gravimetrically as BeO, the mercury being determined gravimetrically as HgS, and the chlorine being determined, after the mercury had been precipitated out, by a Volhard titration with a 0.1 N solution with silver nitrate.

This analysis yielded the following results, in per cent (Table 2).

TABLE 2

	I	II	III	Mean of 3 determinations
Beryllium	1.91	1.95	1.94	1.93
Mercury	42.78	42.69	42.74	42.74
Chlorine	30.12	30.29	30.28	30.23
Water (by differences)	25.18	25.07	25.03	25.10

Crystallization was extremely slow. It took two weeks to secure the amount of salt required for analysis. The individual identity of the salt was checked during crystallization by observing the shape of the crystals through a microscope. It should be noted that a separate observation was required to check on the purity of the crystallized salt, inasmuch as we had noted in our work with the iodomercurates that several salts, differing in composition and crystalline form, could be secured in a certain sequence from a single solution during the concentration process. We have observed this phenomenon in the iodomercurates of calcium, barium, lithium, and other metals.

The crystals collected during all this time were square lemon-yellow platelets. These platelets grew together during the process of crystallization, forming clusters. The crystals were lighter than the mother liquor and floated on its surface. The crystals were filtered out of the mother liquor in an atmosphere of dry air and then analyzed, the results of analysis being shown in Table 3.

TABLE 3

No.	Determination of chlorine			Determination of Hg		Determination of beryllium			Per cent H_2O (by differences)
	Grams of the salt	Ml of 0.1 N $AgNO_3$	Per cent chlorine	Grams of HgS	Per cent mercury	Grams of the salt	Grams of BeO	Per cent beryllium	
1	0.3870	35.08	33.14	0.2037	45.37	0.7139	0.0402	2.03	20.46
2	0.3557	32.18	32.08	0.1865	45.24	0.7967	0.0442	2.00	20.68
3	0.4117	37.20	32.04	0.2172	45.48	0.6602	0.0386	2.01	20.47
Average			32.09		45.36			2.01	20.55
Calculated from the formula: $Be[HgCl_4]\cdot 5H_2O$			32.12		45.44			2.04	20.38

The simplest formula corresponding to the composition indicated by analysis: $BeCl_2 \cdot HgCl_2 \cdot 5H_2O$.

The synthesized salt may be assigned the formula of $Be[HgCl_4]\cdot 5H_2O$, in accordance with the concepts of Dobroserdov [5]. The formation of such a salt is borne out by the negative reaction for free mercury ions.

Properties. Solubility in water at 15°: 95%. The crystals of $Be[HgCl_4]\cdot 5H_2O$ are very hygroscopic. When about 1 gram of the salt was allowed to stand in air of ordinary humidity and temperature, it deliquesced completely within 5-6 minutes. A freshly prepared (1:200) solution of this salt is more stable than a solution of beryllium iodomercurate, no mercury ions being detected during the first 3-5 minutes of passing hydrogen sulfide through the solution, whereas mercuric sulfide is thrown down at once by hydrogen sulfide from a solution that has stood for a while.

$Be[HgCl_4]\cdot 5H_2O$ gradually loses moisture when standing in a desiccator over sulfuric acid (sp.gr. 1.84); the loss of water after 7 days is about 4%, equivalent to 1 mole of water, the surface of the initially transparent and lustrous crystals becoming dull. Keeping the crystals in the desiccator for a longer period caused no further change in weight or in external appearance. The crystals fume slightly when exposed to air, giving off HCl.

Drying at 85° results in a loss of 12.5-13% of the crystallization water, equivalent to 3 moles of H_2O. Further drying at this temperature results in decomposition of the salt, with partial evolution of $HgCl_2$, the salt not melting thereby. $Be[HgCl_4] \cdot 5H_2O$ is readily soluble in methanol and in ethyl and amyl alcohols. It is slightly soluble in toluene, benzene, and chloroform and very slightly soluble in carbon tetrachloride.

Dissolution is accompanied by decomposition of the complex salt into simple chlorides in all these solvents.

Preparation of Basic Beryllium Chloromercurate

The basic beryllium chloride required for the synthesis of basic beryllium chloromercurate was prepared by dissolving metallic beryllium in concentrated hydrochloric acid (36%), 1 gram-atom of Be being used per mole of HCl. Prolonged heating on a water bath was required to dissolve all the beryllium.

The results of analysis of the colorless, heavy solution are given in per cent in Table 4.

TABLE 4

	I	II	III	Mean of 3 determinations
Beryllium	6.36	6.39	6.48	6.41
Chlorine	25.12	25.23	25.26	25.20
H_2O + OH (by differences)	69.52	69.39	69.39	69.43
	69.52	69.39	69.39	69.43

The analysis findings indicated that the solution had the following composition: $BeOHCl + 4.4H_2O$. 100 grams of the solution at 15° contained 43.71 g of BeOHCl.

The resultant solution of basic beryllium chloride was saturated in the cold with mercuric chloride. The following proportions by weight were employed, by analogy with the beryllium iodomercurate we had synthesized previously and in conformity with the concepts of Dobroserdov [5]: 1) 1 mole of $HgCl_2$ per mole of BeOHCl; and 2) 2 moles of $HgCl_2$ per 3 moles of BeOHCl.

All the calculated mercuric chloride dissolved in both cases, no free mercury ions being found in either solution, whereas the reaction for the beryllium ion was positive, indicating that a beryllium chloromercurate had been formed.

When these solutions were concentrated over H_2SO_4 (sp. gr. 1.84) at 15-16°, it took 37 days for crystals to separate out of the first solution and 24 days from the second. The crystals were of the same crystalline form in both cases and, as we later found, of the same chemical composition.

The per cent composition of the first and second mother liquors at the onset of crystallization is given in Tables 5 and 6.

TABLE 5 Solution I

	I	II	III	Mean of 3 determinations
Beryllium	2.18	2.16	2.16	2.17
Mercury	48.58	48.69	48.83	48.70
Chlorine	25.86	25.65	25.77	25.76
H_2O + OH (by differences)	23.38	23.60	23.24	23.37

TABLE 6 Solution II

	I	II	III	Mean of 3 determinations
Beryllium	2.91	2.94	2.93	2.93
Mercury	43.84	43.69	43.75	43.76
Chlorine	27.06	27.16	27.03	27.08
H_2O + OH (by differences)	26.19	26.21	26.29	26.23

Composition of Solution I: $BeOHCl \cdot HgCl_2 + 4.4H_2O$. 100 g of the solution at 15° contained 80.70 g of $BeOHCl \cdot HgCl_2$.

Composition of Solution II: $3BeOHCl \cdot 2HgCl_2 + 10.4H_2O$. 100 g of the solution at 15° contained 85.80 g of $3BeOHCl \cdot 2HgCl_2$.

The first and second solutions crystallized differently. The crystals settled out of Solution I gradually, in the course of 4-5 days. A small quantity of crystals settled out of Solution II at once, and three days later the whole solution turned into a solid crystalline mass, adhering solidly to the crystallizer.

The crystals, which were separated from both mother solutions in an atmosphere of dry air, were analyzed, the analysis indicating that they were alike.

The composition of the crystals in the first and second series of tests is given in Table 7.

TABLE 7

Series I

No.	Determination of chlorine			Determination of Mercury		Determination of beryllium			Per cent H_2O + OH (by differences)
	Grams of the salt	Grams of 0.1 N $AgNO_3$	Per cent chlorine	Grams of HgS	Per cent mercury	Grams of the salt	Grams of BeO	Per cent beryllium	
1	0.5098	41.20	28.66	0.3212	54.12	0.9261	0.0814	2.36	14.83
2	0.5067	40.84	28.58	0.3190	54.28	0.8255	0.0545	2.38	14.76
3	0.5459	44.15	28.68	0.3430	54.17	0.7888	0.0538	2.46	14.69
	Average		28.64	–	54.19	–	–	2.41	14.76
Series II									
1	0.4375	35.40	28.69	0.2745	54.09	0.7180	0.0480	2.41	14.81
2	0.4739	38.52	28.82	0.2982	54.24	0.6038	0.0408	2.44	14.50
3	0.3744	30.24	28.64	0.2353	54.18	0.7776	0.0552	2.42	14.76
	Average		28.72	–	54.17	–	–	2.42	14.69
	Calculated from the formula: $BeOH[HgCl_3]\cdot 2H_2O$		28.83	–	54.37	–	–	2.44	14.37

The composition of the crystals as established by analysis was $BeOHCl\cdot HgCl_2\cdot 2H_2O$ or, by analogy with the beryllium iodomercurate we have synthesized $BeOH[HgCl_3]\cdot 2H_2O$. The synthesized salt may be regarded as a derivative of the acid $H[HgCl_3]\cdot H_2O$.

The water in the crystal hydrates of the beryllium chloromercurates was also determined by the hydride method by A. G. Elitsur, the author of that method [6]. His findings coincided with the percentages of water calculated for these salts by the method of differences.

Properties. The solubility of this salt in 100 g of solution at 15° is 90.0 grams. The crystals were highly hygroscopic; they greedily absorbed moisture from the air, becoming wet very fast. Dissolution in water was slower than with the other halogenomercurates, without any decomposition. A freshly prepared solution (about 1%) exhibited no free mercury ions during the first few minutes after preparation.

In contrast to the crystals of the normal salt, these crystals lost no crystallization water when kept in a desiccator over sulfuric acid.

The crystals suffered a slight loss of weight when kept in a drying cabinet at 60-80°, this loss totaling 0.5%, equivalent to 0.15 molecule of water.

The crystals begin to break down, without melting, when a temperature of 84° is reached.

The basic beryllium chloromercurate behaves like the normal salt in organic solvents.

SUMMARY

1. The crystal hydrates of the beryllium chloromercurates $Be[HgCl_4]\cdot 5H_2O$ and $BeOH[HgCl_3]\cdot 2H_2O$, which may be regarded as derivatives of the chloromercuric acids $-H_2[HgCl_4]\cdot xH_2O$ and $H[HgCl_3]\cdot xH_2O$ have been synthesized for the first time.

2. In contrast to the beryllium iodomercurates, it proved to be possible to isolate the beryllium tetrachloromercurate $Be[HgCl_4]\cdot 5H_2O$. Therefore, the counterpolarizing effect of the outer sphere proved to be weakened, owing to the fact that the chlorine ion has a smaller radius than the iodine ion.

3. A study of the properties of beryllium chloromercurates has shown that the basic salt $BeOH[HgCl_3]\cdot 2H_2O$ possesses a higher stability than either the normal salt $Be[HgCl_4]\cdot 5H_2O$, or the basic beryllium

iodomercurate $BeOHI \cdot 2BeOH[HgI_3] \cdot 6H_2O$.

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BERYLLIUM BROMOMERCURATES

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Very little research has been done on the double salts of beryllium bromides and the bromides of other light metals with mercuric bromide. The data in the literature are not always accurate, often requiring further investigation. Until recently not one double salt of the bromides of metals in Group II of the periodic system with mercuric bromide had been isolated in the crystalline state. It is stated in the literature that only in solution have the following salts been prepared: $MgBr_2 \cdot HgBr_2$, $CaBr_2 \cdot HgBr_2$, $BaBr_2 \cdot HgBr_2$ [1], and $SrBr_2 \cdot HgI_2$ [2]. In our investigation of the double halides of beryllium and mercury we have been able to prove experimentally that it is impossible to recover the crystalline double iodides of beryllium and mercury from $BeI_2 \cdot HgI_2$ solutions, owing to the extreme instability of these compounds. The crystal hydrate of the basic beryllium iodomercurate, $BeOHI \cdot 2BeOH[HgI_3] \cdot 6H_2O$, proved to be much more stable. As for the double chlorides of beryllium and mercury, the smaller radius of the chlorine ion made the normal beryllium chloromercurate, which we isolated as a salt with the composition of $Be[HgCl_4] \cdot 5H_2O$, as stable as the basic beryllium chloromercurate, which we isolated as $BeOH[HgCl_3] \cdot 2H_2O$.

The size of the radius of the bromine ion justified the assumption that the stability of beryllium bromomercurates would be higher than that of the iodomercurates and correspondingly smaller than that of the chloromercurates.

These circumstances led us to undertake the present research

Preparation of beryllium bromomercurate was effected by dissolving metallic beryllium in freshly prepared concentrated (46%) hydrobromic acid. Our calculation was based upon the neutral salt, $BeBr_2$. The metal dissolved rapidly, the solution being warmed up considerably. The results of analysis of the colorless solution of beryllium bromide are given in Table 1.

TABLE 1

	I	II	III	Mean of 3 determinations
Beryllium	2.38	2.36	2.45	2.40
Bromine.....	42.38	42.53	42.56	42.53
Water (by differences) ...	55.24	55.11	55.00	55.08

TABLE 2

	I	II	III	Mean of 3 determinations
Beryllium.....	1.36	1.34	1.38	1.36
Mercury	30.56	30.42	30.36	30.45
Bromine.....	48.25	48.32	48.41	48.33
Water (by differences)....	19.83	19.92	19.85	19.87

Composition of the solution: $BeBr_2 + 11.5\,H_2O$. 100 grams of the solution at 15° contained 44.93 g of $BeBr_2$.

The beryllium bromomercurate was prepared by saturating a solution of beryllium bromide in the cold with mercuric bromide, using 1 mole of $HgBr_2$ per mole of $BeBr_2$.

The resultant solution was not very heavy and was colored a reddish-brown. When it was dehydrated in a desiccator over sulfuric acid (sp. gr. 1.84) at 15°, a small amount of a white precipitate of $HgBr_2$ settled out on the second day; the solution was carefully decanted from this precipitate. As concentration was continued, the color of the solution grew deeper, and large amounts of HBr were evolved. Crystallization set in after three months had elapsed. The specific gravity of the mother liquor was d_{15}^{15} 3.28.

The results of analysis of the solution are given in Table 2.

Composition of the solution: $BeBr_2 \cdot HgBr_2 + 7.2H_2O$. 100 grams of the solution at 15° contained 80.30 g of $BeBr_2 \cdot HgBr_2$.

The crystals were filtered out of the mother liquor in an atmosphere of dry air and then analyzed; the results of analysis are given in Table 3.

TABLE 3

No.	Determination of bromine			Determination of mercury		Determination of beryllium			Per cent water (by differences
	Grams of salt	Ml of 0.1N $AgNO_3$	Per cent bromine	Grams of HgS	Per cent Mercury	Grams of salt	Grams of BeO	% beryllium	
1	0.5600	36 14	51.58	0.2089	32.18	1.1021	0.0428	1.40	14.85
2	0.5807	37.40	51.47	0.2185	32.44	1.2211	0.0481	1.42	14.67
3	0.4779	30.80	51.51	0.1795	32.38	1.3166	0.0504	1.38	14.73
	Average		51.52		32.33			1.40	14.75
	Calculated from the formula:								
	$Be[HgBr_4] \cdot 5H_2O$		51.62		32.39			1.46	14.53

The analytical findings enable us to represent the composition of the synthesized salt by the formula $BeBr_2 \cdot HgBr_2 \cdot 5H_2O$ or $Be[HgBr_4] \cdot 5H_2O$.

The analytical findings exhibit no significant deviation from the values calculated from the formula.

Properties. The crystals were thin platelets, of the color of bromine water, piled one on top of the other. Like the mother liquor, the crystals fumed when exposed to air, giving off hydrogen bromide. They were 94.70% soluble in water at 15°. The salt was very highly hygroscopic, absorbing moisture from the air and rapidly dissolving. No mercuric bromide was evolved during the process.

Keeping the crystals in a desiccator over concentrated sulfuric acid resulted in a slight loss of weight. The loss of weight totalled some 3% after 3 days, the equivalent of one molecule of water; the surface of the crystals was covered with a slight white film and more hydrogen bromide was given off. The crystals melted in their own crystallization water when they were heated to 30°, decomposing and giving off $HgBr_2$ when heated to 70°. The salt lost about 9% of its water when dried in a drying cabinet, the equivalent of 3 molecules of water. Beryllium bromomercurate is readily soluble in methanol and in ethyl and amyl alcohols, very slightly soluble in toluene and benzene, and practically insoluble in chloroform and carbon tetrachloride. Dissolution in these solvents involves decomposition of the coordination compound into the simple salts.

Preparation of basic beryllium bromomercurate. Basic beryllium bromide was prepared by dissolving metallic beryllium in strong HBr, the proportions being 1 mole of HBr/gram-atom of Be.

The mixture had to be heated on a water bath for several days for all the beryllium to dissolve. The colorless solution was very dense; its percentage composition is given in Table 4.

TABLE 4

	I	II	III	Mean of three determinations
Beryllium	4 27	4.36	4.36	4.31
Bromine	38.27	38.39	38.30	38.32
H_2O + OH (by differences)	57.46	57.25	57.34	57.35

TABLE 5

	I	II	III	Mean of three determinations
Beryllium	2.34	2.30	2.29	2.31
Mercury	34.31	34.43	34.13	34.29
Bromine	47.98	47.77	47.71	47.83
H_2O + OH (by differences)	15.37	15.50	15.87	15.58

Composition of the solution: $BeOHBr + 5.7H_2O$. 100 grams of the solution at 15° contained 50.80 grams of BeOHBr. The basic beryllium bromomercurate was prepared by saturating the prepared solution with mercuric bromide, the proportions used being as follows: 1) 1 mole of $HgBr_2$ per mole of BeOHBr; and 2) 2 moles of $HgBr_2$ to 3 moles of BeOHBr (this ratio of the parts by weight of mercuric bromide and basic beryllium bromide placed in reaction together corresponded to the ratio of mercuric iodide to basic beryllium iodide at which the two combined to constitute the basic beryllium iodomercurate). All the $HgBr_2$ dissolved in the cold in both instances. Both solutions exhibited a positive reaction for the Be ion with gaseous ammonia and a negative reaction for the mercury ion when hydrogen sulfide was passed through the solution. This showed that a beryllium bromomercurate had been formed in the solution.

When the solutions were concentrated in a desiccator over sulfuric acid (sp. gr. 1.84) at 14-16°, they gradually turned brown, taking on the color of bromine water.

Crystals were detected in the second solution after 29 days had elapsed, the specific gravity of the mother liquid being d_{15}^{15} 3.48.

The mother liquid was analyzed, the results being tabulated in per cent in Table 5.

Solution composition: $3BeOHBr \cdot 2HgBr_2 + 7.4H_2O$.

100 grams of the solution at 15° contained 88.70 grams of $3BeOHBr \cdot 2HgBr_2$. The mother liquor was extremely unstable when diluted: the addition of a single drop of water produced the instantaneous decomposition of the complex salt at the point where the water entered, $HgBr_2$ being evolved.

The crystals filtered out of the mother liquor in dehydrated air were analyzed chemically, the results being listed in Table 6.

TABLE 6

No.	Determination of bromine			Determination of mercury		Determination of beryllium			Per cent H_2O + OH (by differences)
	Grams of salt	Ml of 0.1N $AgNO_3$	Per cent bromine	Grams of HgS	Per cent Mercury	Grams of salt	Grams of BeO	% beryllium	
1	0.5181	30.80	47.51	0.2380	39.61	1.4710	0.0702	1.72	11.16
2	0.6135	36.57	47.64	0.2832	39.79	1.0750	0.0540	1.81	10.76
3	0.6578	39.19	47.65	0.3048	39.94	1.0250	0.0506	1.78	10.68
	Average		47.60		39.78			1.77	10.85
	Calculated from the formula:								
	$BeOH[HgBr_3] \cdot 2H_2O$		47.72		39.93			1.79	10.54

The analysis data enable us to represent the composition of the crystals as follows: $BeOHBr \cdot HgBr_2 \cdot 2H_2O$.

The experimental results are in good agreement with those calculated from the formula.

It took much longer for crystallization to commence in the first solution than in the second. Analysis indicated that the crystals recovered from the first and second solutions had the same chemical composition and the same crystalline form. The number of water molecules in the crystal hydrates of the beryllium bromomercurates was also determined by the direct method by A. G. Elitsur, the originator of this method [3]. The results of this determination agreed with the percentage of water in these salts as calculated by the differences.

Properties. The $BeOH[HgBr_3] \cdot 2H_2O$ crystals were light-orange in color. They were hard and brittle, readily crumbling when pressed with a rod. They greedily absorbed moisture from the air, rapidly dissolving, and then decomposing with the evolution of $HgBr_2$.

When the crystals were kept in a desiccator over concentrated sulfuric acid (sp. gr. 1.84), they turned into a solid hyaline mass, though their weight remained unchanged.

The salt began to decompose when heated to 85°, without melting. Keeping the salt in a drying cabinet at a temperature slightly below the decomposition temperature caused a slight loss of weight, 0.5%, equivalent to 0.15 molecule of water.

The basic beryllium bromomercurate behaves like all the other beryllium halogenomercurates in organic solvents.

SUMMARY

1. The crystalline beryllium tetrabromomercurate pentahydrate, $Be[HgBr_4] \cdot 5H_2O$, has been prepared and isolated for the first time by reacting a solution of beryllium bromide with mercuric bromide.

The properties of this hydrate indicate that it may be regarded as the beryllium salt of bromomercuric acid: $H_2[HgBr_4] \cdot xH_2O$.

2. Reacting a solution of basic beryllium bromide with mercuric bromide yields the basic beryllium tribromomercurate, which we have isolated for the first time as a crystal dihydrate, $BeOH[HgBr_3] \cdot 2H_2O$. This hydrate is a derivative of tribromomercuric acid, $H[HgBr_3] \cdot xH_2O$.

3. Comparison of the properties of normal and basic beryllium bromomercurates showed that the basic beryllium bromomercurate possesses higher stability.

4. Comparison of the stability of beryllium chloro-, bromo-, and iodomercurates indicates that the chloro derivative has the highest stability and the iodo one the lowest.

The basic beryllium halogenomercurates are more stable than the normal beryllium tetrahalogenomercurates. As in the normal tetrahalogenomercurates, the stability of the trihalogenomercurates dimishes from chlorine to iodine, which also affects the composition of the basic salts. Whereas the composition of the basic beryllium chloro- and bromomercurates may be represented by the formula $BeOH[HgHa_3] \cdot 2H_2O$, the composition of the basic beryllium iodomercurate isolated under similar conditions is more complex: $BeOHI \cdot 2BeOH[HgI_3] \cdot 6H_2O$.

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ANHYDROUS POTASSIUM METANIOBATE

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Joly [1] produced anhydrous potassium metaniobate by fusing together equimolecular quantities of potassium carbonate, niobium pentoxide, and potassium fluoride, used as a flux.

The first X-ray analysis of anhydrous potassium metaniobate was made by Goldschmidt [2], who showed that $KNbO_3$ has a lattice of the perovskite type with the parameter $a_w = 4.01 \pm 0.02$A. Later, Quill [3] secured a more precise value of the parameter, finding that $a_w = 4.005 \pm 0.02$ A. With this value, we calculated the specific gravity of anhydrous potassium metaniobate as $\underline{d} = 3.634$. There still is no information in the literature on the melting point of $KNbO_3$, its pyknometric specific gravity, or its other constants.

The present research had as its objective the preparation of anhydrous potassium metaniobate by various methods, ascertaining the effect of the methods of preparation upon some properties of the salt, determining its thermal stability at high temperature and its melting point, and finding its pyknometric specific gravity.

Initial Preparations

Niobium pentoxide. A technical mixture "tantalum-niobium" tailings served as the initial raw material for the preparation of pure niobium pentoxide. The mixture contained approximately equal proportions of niobium and tantalum as their fluorides, the principal impurities being compounds of iron, tin, and silicon. The percentage of titanium was negligible. The tailings were processed into pure niobium pentoxide as follows.

A 50-gram batch of the tailings was moistened with water to the consistency of a paste, transferred to a silver cup, and heated with 10 ml of concentrated sulfuric acid until all the hydrofluoric acid had been driven off. Then the entire mass was transferred to a porcelain 1-liter beaker and covered with distilled water, and the mixture thoroughly stirred. The wash waters, which contained large quantities of ferric sulfate, were decanted from the residue. Washing was continued to eliminate all the iron ions and sulfate ions, but it was impossible to eliminate the iron ions completely by this method. The niobium and tantalum oxides, freed of most of their iron, were dried at 120° and then thoroughly mixed with 200 g of a soda-alkali mixture (90% Na_2CO_3 + 10% NaOH). The resultant mixture was sintered in a silver cup; then it was pulverized and treated with cold water, which removed such impurities as tin and silicon, eliminated in the form of stannates and silicates. The alkaline niobates and tantalates produced during sintering remained in the deposit owing to the high alkalinity of the solution. Much of the tin was eliminated from the niobates and tantalates by decanting the alkaline solutions. Not all the tin is eliminated in the shape of stannates at this point [4].

The mixture of sodium tantalates and niobates was dissolved in hot water. The hot solution was treated with hydrochloric acid (1:1), throwing down a voluminous white precipitate of tantalum and niobium pentoxides. The wash waters again exhibited small percentages of iron and tin. All the remaining iron and tin were eliminated by boiling the precipitate with concentrated hydrochloric acid. The mixture of "pentoxides" was washed to remove the traces of hydrochloric acid and then transferred to a lead cup and dissolved in the calculated quantity of 40% hydrofluoric acid. Enough of a potassium fluoride solution was added to the resulting transparent solution to form K_2NbF_7 and K_2TaF_7, plus enough water to keep the acid concentration from exceeding 2%, as indicated by Savchenko and Tananaev [5]. The resulting crystals of potassium fluorotantalate were filtered out on a lead Buchner funnel and washed with a small quantity of cold water. The filtrate and the wash waters, which contained potassium oxyfluoroniobate and traces of potassium fluotantalate, were evaporated to dryness in a lead cup and then heated to 110-120° to eliminate the excess hydrofluoric acid.

To remove all traces of tantalum the crystals of potassium oxyfluoniobate were dissolved in water, the resultant solution being heated on a water bath. To the hot solution there were added 0.5g of hydrofluoric acid and 2 ml of a saturated solution of potassium carbonate. Some time later a minute precipitate

of the salt $K_4Ta_4O_5F_{14}$ settled out; it was filtered out. The filtrate was again evaporated to dryness, and the procedure for removing the last traces of tantalum repeated as described above. No more $K_4Ta_4O_5F_{14}$ was found, an indication of the complete separation of the niobium and the tantalum. The potassium oxyfluoniobate was treated with a 10% solution of ammonia in a lead beaker. The precipitated niobium pentahydroxide was washed with water until all the fluorine ions had been eliminated. After drying and calcining, the niobium pentoxide was a white powder that contained no tantalum pentoxide. A test for titanium was negative.

The potassium carbonate employed in this research was marked "c.p."; it was recrystallized, fused in a platinum crucible, and pulverized. The potassium fluoride was prepared from recrystallized potassium carbonate and purified hydrofluoric acid.

Method of analysis. The percentage of niobium pentoxide in the samples of anhydrous potassium metaniobate was determined by fusing a weighed sample of the salt with ten times its weight of ammonium bisulfate and lixiviating the melt with a 5% solution of ammonium carbonate. The sufate ions could then be readily washed out of the niobium pentahydroxide on the filter. The precipitate on the filter was dried, the filter paper incinerated, and the residue calcined in a porcelain crucible to constant weight, the niobium then being determined as the pentoxide. The percentage of potassium oxide was determined by the method suggested by K. L. Malyarov [6].

EXPERIMENTAL

Preparation of anhydrous potassium metaniobate. Three methods are given in the literature [1, 4, 7] for preparing anhydrous potassium metaniobate; all three were used in our research.

a) Pure niobium pentoxide was fused in a platinum crucible with an equimolecular amount of potassium carbonate and potassium fluoride, used as a flux. After the melt had cooled, the crystalline mass was extracted from the crucible and treated with boiling water to remove the potassium fluoride. Microscopic examination readily demonstrated the crystalline structure of the substance produced. The crystals were cubic, resembling the crystals of sodium metaniobate described by Holmquist [8].

Analysis of the crystals yielded the following results:

0.2347, 0.2084 g substance: 0.1718.0, 0.1421 g Nb_2O_5; 0.0630, 0.0560 g K_2O. Found %: Nb_2O_5 73.19, 73.21; K_2O 26.84, 26.82. $KNbO_3$. Calculated %: Nb_2O_5 73.28; K_2O 26.72.

b) Equimolecular quantities of potassium carbonate and niobium pentoxide were thoroughly pulverized and mixed together and then transferred to a silver crucible. The mixture was heated to 800° in a crucible furnace to drive off all the carbon dioxide. The contents of the crucible were then transferred to a beaker containing hot distilled water to eliminate the minute excess of potassium carbonate. After the crystals had been washed and dried, they were examined under the microscope. They resembled the crystals of potassium metaniobate prepared by the preceding method.

Analysis yielded the following results:

0.1983, 0.2008 g substance: 0.1452, 0.1469 Nb_2O_5; 0.0534, 0.0538 g K_2O. Found %: Nb_2O_5 73.23, 73.20; K_2O 26.83, 26.82. $KNbO_3$. Calculated %: Nb_2O_5 73.28; K_2O 26.72.

c) A mixture of niobium pentoxide and K_2CO_3 in the molecular proportions of 1:5 was mixed and melted over a blowpipe flame. The molten mass was cooled and then lixiviated with a small quantity of cold distilled water. As Bedford had found [9] for sodium niobate, this yielded the salt $Na_{14}Nb_{12}O_{37} \cdot 32H_2O$. In the case of potassium niobate the salt was $K_{14}Nb_{12}O_{37} \cdot 28H_2O$. The potassium niobate was filtered out of the mother liquor and dried in air, after which it was transferred to a platinum crucible and calcined for 2 hours at a temperature in excess of 700°. The salt was first dehydrated and then decomposed, forming $KNbO_3$. The resultant potassium metaniobate was water-insoluble. Microscopic examination revealed that the potassium metaniobate retained the 7:6 form of salt crystals (minute, stub prisms).

Analysis yielded the following results:

0.1549, 0.1809 g substance: 0.1133, 0.1325 g Nb_2O_5; 0.0413, 0.0482 g K_2O. Found %: Nb_2O_5 73.15, 73.24; K_2O 26.68, 26.62. $KNbO_3$. Calculated %: Nb_2O_5 73.28; K_2O 26.72.

In view of the fact that there is no information in the literature on the pyknometric determination of the specific gravity of potassium metaniobate, we were interested in learning whether the method of preparing this salt had an effect upon its specific gravity. The specific gravity was determined in a pyknometer with toluene. The test data are listed in Table 1.

TABLE 1

Specific Gravity of Anhydrous Potassium Metaniobate Prepared in Different Ways

	Method of preparing anhydrous potassium metaniobate	Specific gravity
1	Fusing equimolecular quantities of Nb_2O_5 and K_2CO_3	4.596
2	Fusing equimolecular quantities of K_2CO_3, KF, and Nb_2O_5 ...	4.588
3	Decomposing $K_{14}Nb_{12}O_{37} \cdot 28H_2O$	4.586
	Mean value	4.590

According to Windmaisser [7], anhydrous potassium metaniobate decomposes at high temperature, yielding an acid niobate of undetermined composition. His paper makes no mention of the temperature at which the potassium metaniobate decomposes.

We made the following test to determine the melting point of potassium metaniobate and to ascertain its thermal stability at high temperature. A platinum crucible containing 2 g of anhydrous potassium metaniobate was placed in a crucible furnace heated to 1200°. A pyrometer with a platinum-platinum-rhodium thermocouple that had been previously calibrated with $K_2Cr_2O_7$, NaCl, and K_2SO_4 was used to measure temperatures. The potassium metaniobate melted completely at 1200°. One end of the thermocouple, protected by a platinum tip, was immersed in the molten salt. The melting point was determined from the cooling curve. The salt was heated to fusion and the melting point was determined three times. Substituting a corumdum crucible for the platinum one made no difference in the shape of the cooling curve or in the melting point of the salt. The melting point of anhydrous potassium metaniobate was found to be $1184 \pm 2°$.

The cooled melt had a distinctly crystalline structure.

To learn whether potassium metaniobate decomposed at 1200°, the salt was taken out of the crucible and boiled in water. The salt remained insoluble. Analysis indicated its composition was as follows:

0.2013, 0.1890 g substance: 0.1475, 0.1384 g Nb_2O_5; 0.0539, 0.0504 g K_2O. Found %: Nb_2O_5 73.31, 73.23; K_2O 26.79, 26.67. $KNbO_3$. Calculated %: Nb_2O_5 73.28; K_2O 26.72.

The results of analysis show that potassium metaniobate does not decompose when fused.

To ascertain the effect of the method of preparation upon the structure of anhydrous potassium metaniobate we made an X-ray analysis of two samples of $KNbO_3$. The photograph was taken with FeK_α rays.

The diameter of the chamber was close to 57.3 cm, sodium chloride serving as the standard substance. The measurements are listed in Tables 2 and 3.

Comparing the Debye crystallograms, as well as the values of $\underline{d}$, $\sin\theta$, and $\sin^2\theta$ listed in the tables, we readily see that they are identical. Calculations indicate that anhydrous potassium metaniobate has a lattice parameter $\underline{a}_w = 4.007 \pm 0.003$A.

The specific gravity calculated by Quill from X-ray data is inaccurate, since he used an atomic weight of 93.3 for niobium.

Substituting the value of the lattice parameter $\underline{a}_w = 4.007 \pm 0.003$ A in the formula for density derived in that paper and taking the atomic weight of niobium as 92.91, we get:

$$d = \frac{1 \cdot 179.92 \cdot 1.65 \cdot 10^{-24}}{(4.007 \cdot 10^{-8})^3} = 4.614.$$

This research demonstrates that the crystalline structure, lattice parameter, and specific gravity of anhydrous potassium metaniobate are unaffected by the method used in its preparation.

TABLE 2

$KNbO_3$, Prepared by Reacting Equimolecular Quantities of K_2CO_3, KF, and Nb_2O_5

FeK_α, λ = 1.932 A, 30 kilovolts, 40 milliamps/g

No.	hkl	Intensity	I corrected	a	θ	sin θ	$\sin^2\theta$	$\sin^2\theta = q(h^2 + k^2 + l^2)$
1	—	1	12.83	—	12°50'	0.2221	—	—
2	100	10	13.97	4.006	13 57	0.2411	0.05817	1X0.05817
3	—	4	17.75	—	17 45	0.3048	—	—
4	110	10	19.97	2.831	19 57	0.3413	0.11652	2X0.05826
5	111	1	23.68	2.314	24 41	0.4176	0.1744	3X0.05813
6	—	2	25.64	—	25 38	0.4326	—	—
7	200	9	28.85	2.003	28 51	0.4826	0.2339	4X0.05822
8	210	7	32.65	1.791	32 39	0.5394	0.2910	5X0.05819
9	211	10	36.22	1.636	36 12	0.5905	0.3487	6X0.05811
10	220	10	42.97	1.418	42 57	0.6817	0.4647	8X0.05809
11	221	7	46.33	1.336	46 20	0.7234	0.5233	9X0.05814
12	310	8	49.63	1.268	49 38	0.7619	0.5804	10X0.05804
13	311	4	53.05	1.209	53 03	0.7990	0.6384	11X0.05804
14	—	1	55.13	—	55 08	0.8205	—	—
15	322	7	56.65	1.156	56 39	0.8354	0.6971	12X0.05809
16	320	4	60.37	1.112	60 22	0.8691	0.7554	13X0.05811
17	321	10	64.38	1.080	64 23	0.9017	0.8130	14X0.05807

Note: For FeK_α $\sin^2\theta = 0.05813 (h^2 + k^2 + l^2)$; $a_w = 4.006 \pm 0.002$ A.

TABLE 3

$KNbO_3$, Prepared by Decomposing $K_{14}Nb_{12}O_{37} \cdot 28H_2O$

FeK_α, λ = 1.932 A, 30 kilovolts, 40 milliamps/g

No.	hkl	Intensity	I corrected	a	θ	sin θ	$\sin^2\theta$	$\sin^2\theta = q(h^2 + k^2 + l^2)$
1	—	1	12.86	—	12°52'	0.2227	—	—
2	100	10	13.98	4.007	13 58	0.2412	0.05818	1X0.05818
3	—	1	18.33	—	18 20	0.3148	—	—
4	110	10	19.96	2.833	19 57	0.3412	0.11644	2X0.05822
5	111	2	24.70	2.311	24 42	0.4179	0.1747	3X0.05823
6	—	3	26.41	—	26 25	0.4449	—	—
7	200	8	28.84	2.002	28 50	0.4824	0.2327	4X0.05817
8	210	8	32.63	1.791	32 38	0.5391	0.2907	5X0.05814
9	211	10	36.22	1.634	36 13	0.5909	0.3491	6X0.05819
10	220	10	43.03	1.415	43 02	0.6824	0.4657	8X0.05821
11	221	6	46.33	1.335	46 20	0.7233	0.5232	9X0.05813
12	310	8	49.73	1.266	49 44	0.7630	0.5818	10X0.05818
13	311	5	53.14	1.207	53 08	0.8001	0.6402	11X0.05820
14	—	10	54.32	—	54 19	0.8123	—	—
15	222	10	56.72	1.155	56 43	0.8360	0.6983	12X0.05819
16	320	3	60.42	1.111	60 25	0.8697	0.7563	13X0.05818
17	321	8	64.50	1.076	64 30	0.9026	0.8148	14X0.05815

Note For FeK_α $\sin^2\theta = 0.05818 (h^2 + k^2 + l^2)$; $a_w = 4.007 \pm 0.003$ A.

SUMMARY

1. Anhydrous potassium metaniobate, produced in three different ways, has been investigated.

2. The melting point of anhydrous potassium metaniobate has been found to be 1184 ± 2°.

3. It has been proved that anhydrous potassium metaniobate does not undergo decomposition when fused.

4. It has been found that the crystallographic habit of anhydrous potassium metaniobate varies with the method of preparation.

5. It has been shown that the unit cell of the space lattice of anhydrous potassium metaniobate belongs to the cubic system, no matter what the method used in its preparation, with a lattice parameter of $a_w = 4.007 \pm 0.003$ Å.

6. The specific gravity of anhydrous potassium metaniobate is 4.590 as determined pyknometrically in toluene, this figure being close to the value of 4.614 derived from the X-ray measurements.

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THE DENDRITIC CRYSTALLIZATION OF VARIOUS SALTS FROM AQUEOUS SOLUTIONS

I. THE FORMATION OF DENDRITIC CRYSTALS OF NH_4Cl, KCl, AND NaCl AND THEIR MODIFICATION BY VARIOUS IMPURITIES

Yu. Ya. Tilmans

In a series of previous papers [1] the author has investigated the features involved in the production of dendritic forms of growth of crystals of NH_4Cl and NH_4Br and the modifying action of traces of ions of various metals upon the habit of these crystals. He found that the presence of various cations in the solution always produces the same sequence of changes in the crystal habit of NH_4Cl and NH_4Br.

Under ordinary conditions these substances crystallize only as treelike formations—dendrites. It is impossible to secure crystals of these salts with regular faces no matter how the physical conditi ons of crystallization (degree of solution supersaturation, solution viscosity, or rate of temperature drop) are varied.

Gradually adding impurities of various ions to the solution produces a change in the external faceting of the crystals. Instead of dendrites, we get crystals of stellate, four-petaled, four-sectored, and finally cubic form, depending upon the concentration of the impurity. Even when the effect of the impurity is slight, yielding only imperfect, intermediate crystalline forms, the sequence of habit changes persists. A sharp change in the habit of the crystals, namely, a change from dendrite to cube, is attained after a certain percentage of the impurity of the given ion has been added at the given temperature.

The molar concentration of cations in solution required for a sharp change in faceting is an index of the intensity of the effect of the ion upon the external faceting of the crystals.

The hypothesis, based upon the results of research, that a given percentage of one impurity may be replaced by a corresponding ("equivalent") percentage of another was also tested in the crystallization of ammonium chloride and bromide in the presence of traces of various pairs of ions ($Fe^{+++} + Ni^{++}$, $Fe^{+++} + Co^{++}$, $Fe^{+++} + Cd^{++}$, $Ni^{++} + Ca^{++}$, and the like).

The results of these tests showed that the action of any percentage of any one impurity in a solution may be supplemented by a certain quantity of another, corresponding to the required concentrations of each of these ions when they act independently upon the faceting of crystals.

When the temperature drop used in crystallization is made steeper, and, hence, the change in the degree of supersaturation with time becomes more rapid, the action of impurities grows weaker, a higher impurity concentration being required for achieving a sharp change in the crystal habit. Further research on the effect of various ions as impurities in the solution has yielded similar results. The homotypy of the action of several ions upon the crystalline form of NH_4Cl and NH_4Br, the identical sequence of formation of the same series of crystalline forms in every instance, and the additivity of the action of these impurities lead us to conclude that the faceting of crystals is influenced by a single factor, related to the orienting field of force of the given ion and to its adsorption at the active centers on the various faces of the crystals.

In the ions tested as impurities the intensity of their action upon crystal form rises parallel with the increase in the ion's field of force, and the impurity concentration required to produce a given effect—the transition from the dendrite form to the cubic form of the crystals—diminishes accordingly. As to the reasons for the dendritic crystallization of various substances from a melt or from solution, they are unknown at the present time.

According to Lehmann [2], the crystallization of salts from solution as dendrites involves a locally repetitive change in concentration. The solution is periodically rendered poorer in nutrient material in the layers directly adjacent to the nascent seed crystals, owing to the increased rate of deposition of the substance. With

the emergence of density differences in various layers of the liquid, convection and diffusion currents begin to level out the concentration throughout the liquid, again making the solution supersaturated, again intensifying the deposition of the substance, and forming dendritic branches.

A similar change in concentration and the formation of dendrites takes place during crystallization from the molten state, owing to the liberation of the latent heat of fusion by the nascent crystals, which, in turn, causes a transitory superheating of the liquid in the proximity of the crystals and hence, a retardation of crystallization. After the heat has been dissipated to the surrounding layers, increased crystallization resumes.

A. V. Subnikov [3] believes that the uneven diffusion of the substance into various parts of the crystal whenever the viscosity of the solution is high is the major reason for the production of dendritic forms. The edges and vertices of the crystals obtain much more of the nutrient material than do the faces.

V. D. Kuzbetsov [4] maintains that the presence of impurities in the solution is the cause of dendrite formation.

Petrov and Bukhanova [5], employing the Gibbs-Curie-Wulff principle (of minimum surface energy) and the Bravet principle (of maximum reticular density), regard the formation of dendrites in crystallization from molten metals as due to the higher surface energy of the crystal's vertices and edges, compared to that of its faces. The unlike tendencies of different metals to form dendrites is attributable, in the opinion of these authors, to the very nature of the crystal, its lattice structure.

Opinions also differ as to what a dendrite is. Some researchers (Bochvar, Tammann, etc. [6]) maintain that a metallic dendrite is a treelike crystal growing out of a single center.

Other authors, such as Oknov and Gaev [5] believe that dendrites are junctions of separate crystalline aggregates, oriented in a certain way because of various factors (heat transfer, field of force, etc.).

According to Slavinsky [5], a dendrite is a twinned formation, growing simultaneously along three axes.

The present research has as its objective a study of the conditions governing the constitution of dendritic forms during the crystallization of various salts from solution and the feasibility of modifying these forms when various impurities are present. We have chosen ammonium, sodium, and potassium chlorides as subjects of investigation, the first crystallizing solely in dendrites under ordinary conditions, the second exhibiting a tendency toward dendritic crystallization, and the third exhibiting these forms only under exceptional conditions.

EXPERIMENTAL METHOD

Solutions of NH_4Cl, NaCl, and KCl, saturated at various temperatures, were employed in our crystallization tests. Gelatin, agar-agar, glycerol, and alcohol were added portionwise to identical volumes of these solutions, after which a drop of the solution was spread in a thin layer on a glass slide and examined under the microscope. The impurity was added until the precipitated crystals were predominately dendritic. Then drops of impurity solutions—$FeCl_3$, $CoCl_2$, $NiCl_2$, etc.—were added to these solutions a drop at a time, and the step-by-step reverse transition from the dendritic forms to the initial forms characteristic of these substances was observed microscopically.

The several stages of the dendritic growth of the crystals were photographed.

EXPERIMENTAL

Dendritic crystallization of KCl. 1. KCl crystallizes from aqueous solutions as well-defined cubes. When a drop of an unsaturated solution or a thin layer of the solution on a glass slide is observed under the microscope, we can follow the evolution of dendritic forms (Fig. 1). A square platelet is formed at first, which grows irregularly. A dendrite rapidly develops at one or two vertices of this crystal. [1)]

2. 5 ml of a 1% solution of agar-agar was added to 20 ml of a 10% solution of KCl. The solution was stirred as it was heated to 50°. Then a drop of the solution was placed on a glass slide and slowly evaporated, the temperature of the surroundings being 20°.

1) See plate page 609.

KCl crystallized from such a solution chiefly in the shape of fine branched dendrites, growth usually beginning at the periphery of the drop, the major axis of the dendrite rapidly shifting to the center of the drop, where a few crystals of regular shape settled out. As evaporation continued, a fine network of dendrites also developed between the cubes at the center of the drop. Dendrites were often observed to grow out of the vertices of the cubic crystals (Fig. 2).*)

3. We used 15% and 20% KCl solutions and a solution saturated at 50°, adding 5 ml of agar-agar to each. The crystallization conditions were the same as before.

Microscopic examination disclosed that the higher the temperature drop of KCl crystallization, the harder it was for dendritic forms to arise. We were unable to secure crystals of predominately dendritic form from solutions that were saturated at temperatures only slightly above room temperature.

4. A series of dilute KCl solutions was tested. Drops of solution were slowly evaporated on a glass slide. The lower the concentration of the solution, the fewer regular cubes settled out; then the cubes vanished completely, and crystallization involved nothing but fine, highly branched dendrites.

As the solution concentration was diminished, the percentage of agar-agar required to produce a fully dendritic picture likewise decreased. The gradual addition of agar-agar as an impurity produced a transition from the cube to the dendrite. As a rule, the rupture of the correct form began at vertices of the cube, often at several vertices at once (Fig. 3, a,b).*)

As the concentration of agar-agar in the KCl solution was raised, the cubic crystals disappeared completely, nothing but dendrites settling out and becoming finer and finer and more and more highly branched. A 10% concentration of agar-agar in the solution produced a wholly dendritic crystallization of KCl.

5. Glycerol was tested as an impurity, the crystallization conditions remaining the same. The presence of glycerol heightened the tendency of KCl to develop dendritic forms, but no fine dendrites appeared even when the glycerol concentration in the solution is high.

The gradual transition from the cubic form to the characteristic dendritic form when glycerol was present is exhibited in Fig. 4, a,b,c.*)

When KCl was crystallized from solutions saturated at 50° and above, which contain glycerol, elongated rodlike crystals settled out (Fig. 5).*)

Conversion of the dendritic crystal forms to the cubic under the influence of admixtures of $FeCl_3$, $NiCl_2$, and $CoCl_2$. The powerful effect of the presence of Fe^{+++}, Co^{++}, and Ni^{++} ions in the solution upon the habit of NH_4Cl and NH_4Br has been referred to above, the dendrites being gradually converted into cubes.

In the present research we have studied the effect of the same impurities upon the habit of KCl in solutions to which enough agar-agar had been added to develop dendritic forms.

Effect of Fe^{+++}. We used 20 ml of a 10% solution of KCl + 5 ml of a 1% solution of agar-agar. Drop by drop we gradually added 0.273 mole of $FeCl_3$ per liter as an impurity. The crystallization conditions remained the same as before.

The dendritic form gradually vanished at the center of the drop. The dendritic branches grew thicker, becoming faceted at their ends, the number of branches diminishing, with, finally, only first-order axes left. When more of the impurity is added, well-formed crystals of KCl are formed.

The reverse transition from the dendrite to the cube takes place in the order shown in Table 1.

Individual stages of the reverse transition from the dendritic form to the cubic are shown in Fig. 6, g, h.*)

Effect of Ni^{++}. The crystallization conditions were the same as before. An admixture of an $NiCl_2$ solution was added a drop at a time to a solution of KCl containing agar-agar. The first few drops of $NiCl_2$ caused no noticeable changes: the dendritic crystals retained their shape. As the concentration of the impurity in the solution increased, deformed polyhedra appeared at the center of the drop, with dendrites growing out of their vertices (Fig. 7).*)

A further increase of the $NiCl_2$ concentration in the solution decreased the number of dendrites. Individual dendrites could be seen at the center of the drop, growing out of the crystal vertices, with their branches

*) See Plate, page 609.

TABLE 1

Concentration of impurity, millimoles/liter	Change in crystal habit
0.5	Large number of fine dendrites, some cubes, from whose vertices dendrites grow (Fig. 6, a,b).*
8 7	The number of dendrites drops. The ends of the branches become faceted. Large number of square platelets and cubes (Fig. 6, c,d). *
30	Only the thickened first-order axes are left of the dendritic form, exhibiting only stubby, faceted growths instead of the lateral branches; some platelets and cubes (Fig. 6, e). *
41	No dendrites, large number of true cubes and platelets. Only in rare crystals is there still a tendency toward the growth of dendrites from their vertices (Fig 6, f). *

acquiring facets at their tips. When the concentration of $NiCl_2$ in the solution reached 178 millimoles per liter, the dendrites vanished.

Effect of Co^{++}. Adding $CoCl_2$ to a KCl solution containing agar-agar produced a similar result. All the dendritic forms disappeared when the concentration of the impurity in solution was 194 millimoles per liter.

Dendritic crystallization of NaCl. NaCl crystallizes from an aqueous solution as cubes, no matter what the temperature drop of crystallization. The dendritic forms appear only when a thin layer of solution, produced by simply immersing a glass slide in the solution, is evaporated. This produces skeletal forms. Quicker evaporation of the drop by means of an air jet, with the resulting rapid change in the degree of supersaturation, causes the usual dendrites to form.

Effect of the admixture of agar-agar. We added 10 ml of a 1% solution of agar-agar to 20 ml of an NaCl solution saturated at 25°. The temperature of the surrounding environment was 20°. Dendrites began to grow at the edges of the drop, cubes and square platelets settling out at the center, after which the intervening space filled up completely with thin, finely-branched dendrites. Dendrites grew out of the vertices of several cubes, as in the case of the KCl.

When glycerol was present, the NaCl crystallized in forms resembling those found in the KCl (Fig. 4).* The addition of ethyl, butyl, or isoamyl alcohol promotes the crystallization of the NaCl as elongated rodlike crystals.

Conversion of the dendritic form of NaCl into the cubic when admixtures of $FeCl_3$, $NiCl_2$, or $CoCl_2$ are present. Numerous tests have shown that admixtures of Fe^{+++}, Ni^{++}, and Co^{++} in the solution cause a step-by-step conversion of the dendritic form into the cubic at a certain concentration of the admixture.

The limiting admixture concentrations that cause the total conversion of the NaCl dendrites into cubes are lower than in the crystallization of KCl.

Dendritic crystallization of NH_4Cl and the effect of impurities upon the faceting of the crystals. Ammonium chloride always crystallizes from aqueous solutions in dendrites, no matter what the crystallization conditions may be. At gradual temperature drops and, hence, slight changes in the supersaturation conditions with time and low crystallization rates, the dendrites are formed in the following sequence (Fig. 8).

Figure 8.

At first we see a spherical crystal being formed within the field (a). When the crystal has reached a certain size, we see it turning into a rounded square (b), and then into a star (c), the tips of which grow rapidly to

*) See plate, page 609.

form a cross (d) with rounded ends. These microscopic observations can be made by evaporating a drop of the solution slowly on a glass slide.

When the degree of supersaturation and the crystallization rate are high, finely-branched dendrites are observed. The first-order axes of these dendrites, shaped like sharp arrows, travel rapidly from one edge of the drop to another. Side branches grow simultaneously, but at a slower rate, most often at right angles to the first-order axis.

The addition of various amounts of agar-agar, or ethyl, butyl, or amyl alcohol produced no change in the dendritic forms.

The admixture of $FeCl_2$, $NiCl_2$, or $CoCl_2$ to a solution of NH_4Cl, whether pure or containing various percentages of agar-agar, gradually modifies the shape of the crystals. As the admixtures are added, the usual dendrites are replaced by large arrows, crosses, smaller crosses, rosettes, four-pointed stars, thickened platelets of not quite regular shape, square platelets, and, finally, cubes (Fig. 9).

The concentration of $FeCl_2$ required to convert the dendrites of NH_4Cl into cubes when agar-agar was present was 131 millimoles per liter, or more than when the NH_4Cl was pure (64 millimoles per liter).

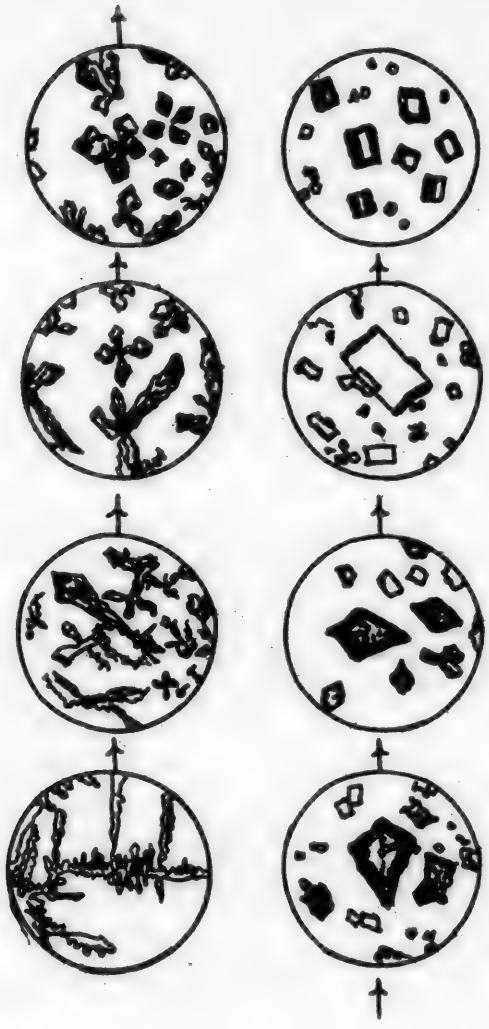

Figure 9

EVALUATION OF RESULTS

1. A detailed study of the conditions governing the crystallization of ammonium, sodium, and potassium chlorides enables us, first of all, to assert that the dendrites of these substances are treelike single-crystal formations, growing out of a single center. This is true both of the formation of a branched dendrite from a seed crystal and of the numerous instances of the growth of dendrites from the vertices of fairly large cubic crystals.

2. The three salts we have investigated differ greatly in their tendency to crystallize in dendritic form. Ammonium chloride yields nothing but dendrites, from a pure aqueous solution as well as when impurities such as agar-agar, glycerol, or alcohol are present.

Potassium chloride forms dendrites under specific crystallization conditions, most readily in the presence of agar-agar, gelatin, and other substances that increase the viscosity of the solution.

Sodium chloride exhibits a lesser tendency to form dendrites, but dendrites are formed when this salt is crystallized from thin solution layers or when an admixture of agar-agar is present.

When it is remembered that many other salts form dendrites under certain conditions, it may be stated that the only role of admixtures of substances that increase the viscosity of the medium and hamper the diffusion of the nutrient material into the growing crystal is to increase the inherent tendency of salts toward dendritic crystallization. This is borne out by the formation of dendrites in sodium chloride.

Considering the separate stages involved in the formation of a dendrite from a cubic crystal of NaCl or KCl, we find that growth occurs chiefly at the vertices of the crystal, as is observed very often in many other substances.

At first, true cubes grow out of the solution drops. When they have reached a certain size and the nutrient material is diminished, uneven surface energy develops at the vertices, edges, and faces.

The uniform growth of the crystal ceases, growth occurring chiefly at the vertices and the regions adjacent to them. The individual stages of dendrite formation are readily visible in the crystallization of KCl (Fig. 1), since its rate of growth is low. This phenomenon is reinforced by nonuniform diffusion of the nutrient material in a viscous medium (in our experiments, by crystallization from a thin layer of the liquid on a glass slide, or in the presence of agar-agar).

As A. V. Shubnikov has shown in his paper [3], the lines of diffusion flow are bent toward the edges and vertices, with their density higher at these points, under any conditions governing the growth of a real crystal.

It may be stated, however, that this nonuniformity is not significant under normal crystallization conditions. As the viscosity of the medium rises, crystal growth begins to depend, more and more, upon diffusion and the preferential access of the nutrient material to its vertices, the surface energy and, hence, the rate of growth of which are greater than that of other elements of the crystals. Under these conditions, the tendency of the substance toward dendritic growth is reinforced. The crystal has, as it were, an opportunity of growing rapidly only as lanceolate, treelike formations.

We may therefore conclude that dendritic forms arise as the result of the combined action of two factors: the relative increase in the surface energy at the vertices and edges of the crystal and, hence, their increased rate of growth, and the uneven diffusion of the nutrient material into various parts of the crystal.

The first of these two factors is an inherent property, more or less, of many substances, depending upon their lattice structure. That is why some substances readily give rise to dendritic forms spontaneously, without any external influence (ammonium chloride and bromide, potash, alum, potassium dichromate, and many others).

Other substances display this tendency only when the degree of supersaturation changes rapidly and diffusion is hampered.

3. In the papers by Rebinder [7], Semenchenko [8], and Serb-Serbina [9], these authors have pointed out that surface-active substances promote fineness of structure and modification of crystal form in metallic and nonmetallic systems. The crystal habit undergoes certain changes as the result of differences in the linear rate of crystallization at various edges, due to the adsorption of impurities.

In the tests we ran, admixtures of agar-agar or glycerol merely accelerated the formation of dendrites. The subsequent addition of admixtures of $FeCl_3$, $NiCl_2$, or $CoCl_2$ to these solutions produced a gradual conversion of the dendrites into cubes via a series of intermediate forms.

The dendritic forms vanish completely at a certain concentration of the impurity in the solution.

A comparison of the limiting concentrations of impurities that produce a conversion of a dendrite into a cube (Table 2) indicates that the greater the tendency of a salt to form dendrites, the higher the ion concentration required to break up the dendritic forms and give rise to well-defined cubes.

We can arrange these impurities in order of decreasing effect upon the faceting of crystals as follows: $Fe^{+++} > Ni^{++} > Co^{++}$, corresponding to the fields of force of these ions.

These results lead us to assume that the active centers of the crystal's surface are charged negatively when one of the ions (in our case, the Cl^- ion) is present in excess, resulting in the adsorption of the cations, Fe^{+++}, Ni^{++}, and Co^{++}.

Adsorption is most intensive at the crystal vertices. This eliminates the preponderant growth of the vertices, and the dendritic form cannot develop. Detailed microscopic examination of all stages of the formation of crystalline forms when these ions are present offers convincing proof of these hypotheses of ours.

When the concentration of the impurity in the solution is below the boundary level, square platelets settle out of the solution and gradually begin to grow. At a certain instant the corners of the square begin to be drawn

TABLE 2

Crystallizing salt	Impurity	Limiting concentration of impurity causing a dendrite-cube conversion, millimoles/liter
NH_4Cl	$FeCl_3$	131
	$NiCl_2$	—
	$CoCl_2$	—
KCl	$FeCl_3$	41
	$NiCl_2$	178
	$CoCl_2$	194
NaCl	$FeCl_3$	10
	$NiCl_2$	124
	$CoCl_2$	126

out, so that further growth yields something approaching a dendritic form. The addition of some more of the impurity gradually offsets this tendency, the growth of the corners being suppressed by the impurity and, finally, cubic formations being produced.

It should likewise be noted that breaking down the dendritic forms produced in the presence of agar-agar or glycerol requires a higher concentration of the impurity ions than when the dendrites are formed without these substances present. This is evidence that agar-agar and other substances increase the tendency of salts to produce dendritic forms at a given concentration in solution.

SUMMARY

1. A study of the crystallization of the salts NH_4Cl, NaCl, and KCl has demonstrated that the dendrites of these substances are single-crystal formations, growing from a single center.

2. The hypothesis is advanced that the production of dendritic forms is due to the combined action of two factors: a) the increased surface energy at the vertices and edges of crystals: this is the basic factor; the tendency to form dendrites is inherent in all three of the salts we have investigated, in different degree, depending upon the structure of their space lattices; and b) the uneven diffusion of the nutrient material into various elements of the crystal.

3. The action of admixtures of agar-agar and glycerol to the solution largely involves a diminution of the rate of diffusion and a promotion of the formation of dendrites.

4. Admixtures of Fe^{+++}, Ni^{++}, and Co^{++} ions retard the rate of growth at the vertices owing to their adsorption at the active centers of the crystal. This causes a marked change in the crystal habit: cubes settle out instead of dendritic forms.

5. The greater the tendency of a given substance to produce dendritic forms, the higher the boundary concentration of impurity ions in the solution required to break down the dendritic forms and convert them into the cubic form.

$$C_{boundary} \text{ for } NH_4Cl > C_{boundary} \text{ for KCl} > C_{boundary} \text{ for NaCl.}$$

6. We can arrange the tested impurity ions in order of decreasing effect upon the external form of crystals as follows: $Fe^{+++} > Ni^{++} > Co^{++}$.

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THE FUSIBILITY OF THE TERNARY SYSTEM: LEAD MONOXIDE – VANADIUM PENTOXIDE – TITANIUM DIOXIDE

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Titanium dioxide has been widely employed as a raw material for manufacturing ceramic condenser materials for the high-frequency radio industry because of its high dielectric susceptibility (> 100). Its high caking temperature and the large negative temperature coefficient of dielectric susceptibility (the temperature coefficient of capacitance ~ -7 to $-9 \cdot 10^{-4}$) make it impossible to employ titanium dioxide in the pure state. To secure ceramic pastes with a temperature coefficient of capacitance close to zero fillers are added to titanium dioxide, but this, as a rule, greatly lowers the dielectric susceptibility as well (from 100 down to 15) [1]. The condenser pastes based on titanium dioxide manufactured at the present time that have a temperature coefficient of capacitance approaching zero all have a dielectric susceptibility that does not exceed 15 (with the sole exception of the tetrabar paste [2]).

It is therefore readily understood that we were greatly interested, from both the practical and the theoretical points of view, in discovering new fillers for titanium dioxide that would lower the temperature coefficient of capacitance of the ceramic pastes to values approaching zero while retaining the high values of dielectric susceptibility.

In our search for such fillers we have produced in our laboratory experimental samples containing lead vanadates that exhibit high values of electric susceptibility (50-70) and temperature coefficients of capacitance ranging from $-7 \cdot 10^{-4}$ to $+16 \cdot 10^{-4}$.

We have made a partial investigation of the fusibility of the ternary system PbO–V_2O_5–TiO_2 in order to ascertain the nature of the reaction of titanium dioxide with lead vanadates.

We employed the visual polythermal method in our research. A mixture of PbO, V_2O_5, and TiO_2 was placed in a platinum furnace and melted in a resistance furnace wound with Kornilov alloy, the temperature being measured by a Pt – Pt-Rh thermocouple that had been calibrated against: chemically pure KNO_3 – m.p. 337°, the KCl – Na_2SO_4 eutectic – m.p. 517°, KCl – m.p. 774°, Na_2SO_4 – m.p. 884°, and K_2SO_4 – m.p. 1069°.

The reagents used were as follows: titanium dioxide – prepared from titanic acid containing 99.5% TiO_2 and 0.5% CaO. The lead monoxide was prepared from the carbonate, produced by precipitation from chemically pure lead nitrate. The V_2O_5 was prepared from commercial ammonium vanadate.

We investigated the PbO – TiO_2 and V_2O_5 – TiO_2 sides, repeated the previous investigation [3] of the PbO–V_2O_5 side, and its internal sections. The experimental data are set forth in Tables 1-11 and in Figs. 1 and 2.

The PbO – TiO_2 side was investigated up to 25 mol.% of TiO_2 (Table 1, Figure 1). The liquidus exhibits one eutectic point at 7.5 mol.% of TiO_2 and 818° and one transition point at 19 mol. % of TiO_2 and 1024°. The mixture consisting of 25 mol. % TiO_2 and 75 mol. % PbO melts at 1120°. At higher percentages of TiO_2 in the mixture, the TiO_2 does not dissolve while appreciable amounts of the PbO are volatilized, indicating decomposition of the compound that crystallizes after the transition point at 818°. The system thus exhibits two incongruently fusing compounds.

The PbO – V_2O_5 side had been investigated by Amadori previously [3]. We confirmed the existence of the congruently fusing compounds $8PbO \cdot V_2O_5$, $3PbO \cdot V_2O_5$, and $2PbO \cdot V_2O_5$. No metavanadate is found on the liquidus, the melt forming a glass in that region.

TABLE 1

Fusibility of the $PbO-TiO_2$ System

No.	Mol. % TiO_2	Temperature at which crystallization set in
1	0.0	884°
2	5.0	839
3	10.0	880
4	15.0	965
5	20.0	1030
6	25.0	1099
7	30.0	Did not fuse
8	35.0	Did not fuse

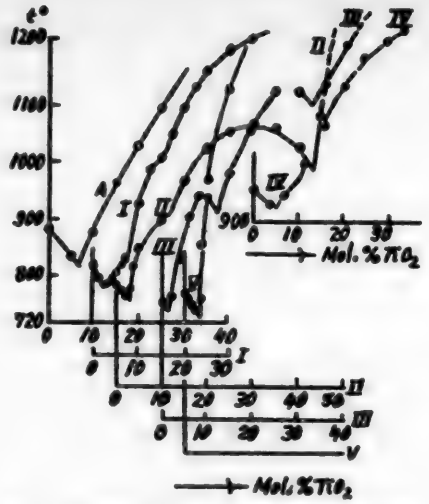

Fig. 1. Fusibility curves of the $PbO-TiO_2$ system (A) and of its sections:

I – 5 mol % V_2O_5 / 95 mol % PbO + TiO_2;

II – 11.1 mol % V_2O_5 / 88.9 mol % PbO + TiO_2;

III – 16 mol % V_2O_5 / 84 mol % PbO + TiO_2;

IV – 25 mol. % V_2O_5 / 75 mol. % PbO + TiO_2;

V – 33.3 mol % V_2O_5 / 66.7 mol % PbO + TiO_2.

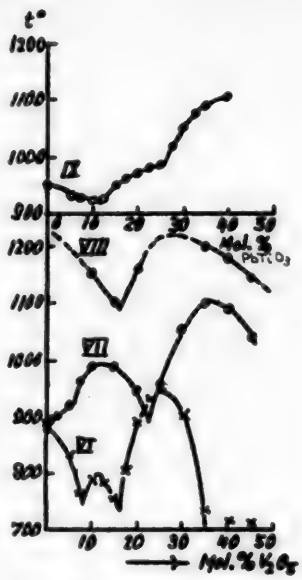

Fig. 2. Fusibility along the sections:

VI – 2 mol.% TiO_2 / 98 mol.% PbO + V_2O_5;

VII – 10 mol.% TiO_2 / 90 mol.% PbO + V_2O_5;

VIII – 25 mol.% TiO_2 / 75 mol.% PbO + V_2O_5;

IX – 25 mol.% V_2O_5 / 75 mol.% PbO + $PbTiO_3$;

The $TiO_2-V_2O_5$ (the third side of the triangle) displays an infinitesimally small mutual solubility.

Section I: 5 mol % V_2O_5 / 95 mol.% PbO + TiO_2. We managed to investigate the fusibility along this section up to 35 mol.% TiO_2. Five separate crystallization phases were found along this portion of the section. PbO crystallizes up to 2 mol % TiO_2, then there comes a transition point at 780°, which is probably followed by the crystallization of the orthotitanate as minute round crystals. A phase not found on the side of the triangle crystallizes as the most minute dust in the interval between 5.5 mol % TiO_2 (815°) and 8 mol % TiO_2 (850°), while the orthotitanate again crystallizes from this phase up to 16 mol.% TiO_2 (1018°). Beyond the transition point (1018°) the compound $PbTiO_3$ crystallizes as large tetrahedral crystals. This phase continues to crystallize up to 35 mol % TiO_2 and 1220°. Adding more titanium dioxide causes minute needles of titantium dioxide to settle out of the melt.

Section II: 11.1 mol % V_2O_5 / 88.9 mol.% PbO + TiO_2. This section has been investigated up to 45 mol.% TiO_2. As we follow the liquidus, the crystallization of $8PbO \cdot V_2O_5$ (from 3 mol % TiO_2 and 765° to 14.5 mol.% TiO_2 and 918°) is followed by the crystallization of the phase consisting of minute dust, the orthotitanate phase observed along Section I being missing, a compound crystallizing as large (larger than 1 mm) four-sided platelets immediately after 14.5 mol.% TiO_2. Along this section the crystallization branch of this compound (the metatitanate $PbTiO_3$) exhibits a distinct maximum at 1170°. The point of joint crystallization of $PbTiO_3$ and TiO_2 occurs at 40 mol % TiO_2 and 420°, after which titanium dioxide crystallized as thin, rather large needles.

Section III: 16 mol. % V_2O_5 / 84 mol.% PbO + TiO_2. This section was investigated up to 41.5 mol.% TiO_2. In addition to the crystallization branch for $3PbO \cdot V_2O_5$, the liquidus distinctly shows other crystallization branches: a phase that crystallizes as dust (Sections I and II) and the metatitanate. Both branches exhibit distinct maxima (Fig. 1).

Section IV: 25 mol. % V_2O_5 / 75 mol. %PbO + TiO_2. This section was investigated up to 33.3 mol. % TiO_2. The liquidus exhibits, in addition to the crystallization branch of $3PbO \cdot V_2O_5$, a short stretch of a phase consisting of fine dust (cf. Sections I, II, and III) and crystals of TiO_2. No metatitanate phase is found.

TABLE 2

Fusibility of the $PbO - V_2O_5$ System

No.	Mol. % V_2O_5	Temp. at which crystallization set in	Remarks
1	0.0	884°	
2	1.6	872	
3	3.5	855	
4	5.1	815	
5	6.0	793	
6	7.7	765	
7	10·0	765	Different phase
8	12.5	793	
9	15.2	748	
10	18.2	781	Different phase
11	21.4	884	
12	23.2	924	
13	25.0	952	
14	26.9	933	
15	29.0	851	
16	33.3	772	
17	38.2	692	
18	43.5	607	Different phase
19	50.0	497	Glass
20	57.2	518	Glass
21	65.4	582	Glass
22	75.0	651	Glass
23	86.4	666	Glass
24	100	675	Glass

TABLE 4

Section II: 11.1 mol. % V_2O_5 + 88.9 mol. % PbO + TiO_2

No.	Mol. % TiO_2	Temp. at which crystallization set in	Remarks
1	0.0	788	
2	1.0	777	
3	2.0	772	
4	3.0	777	
5	4.0	820	Different phase
6	5.0	850	
7	10.0	900	
8	15.0	970	
9	20.0	1128	Different phase
10	25.0	1154	
11	30.0	1168	
12	35.0	1160	
13	40.0	1128	Different phase
14	45.0	1184	
15	50.0	Did not fuse	
16	55.0	Did not fuse	

TABLE 3

Section I: 5 mol. % V_2O_5 + 95 mol. % PbO + TiO_2

No.	Mol. % TiO_2	Temp. at which crystallization set in	Remarks
1	0.0	820	
2	1.0	798	
3	3.0	788	
4	4.0	798	Different phase
5	5.0	809	
6	6.0	820	Different phase
7	7.0	835	
8	10·0	929	
9	12.5	988	
10	15.0	1011	
11	17.5	1053	Different phase
12	20.0	1096	
13	22.5	1135	
14	25.0	1160	
15	30.0	1198	
16	35.0	1220	
17	40.0	Did not fuse	
18	45.0	Did not fuse	

TABLE 5

Section III: 16 mol. % V_2O_5 + 84 mol. % PbO + TiO_2

No.	Mol. % TiO_2	Temp. at which crystallization set in	Remarks
1	0.0	757	
2	2.0	767	Different phase
3	4.0	830	
4	6.0	906	
5	8.0	946	
6	10.0	940	
7	15.0	981	Different phase
8	20.0	1065	
9	25.0	1128	
10	30.0	1128	
11	36.1	1135	Different phase
12	41.5	1190	
13	47.1	Did not fuse	

Section V: $\left.\begin{matrix}33.3 \text{ mol. \% } V_2O_5 \\ 66.7 \text{ mol. \% PbO}\end{matrix}\right\}$ + TiO_2. We were able to trace this section only up to 10 mol. % TiO_2. The liquidus exhibits a single transition point (at 3 mol. % TiO_2 and 734°), the point of joint crystallization of $3PbO \cdot V_2O_5$ and TiO_2 (Figure 1).

Section VI. $\left.\begin{matrix}2 \text{ mol. \% } TiO_2 \\ 98 \text{ mol \% PbO}\end{matrix}\right\}$ + V_2O_5. The following features are displayed by the liquidus: a crystallization branch for PbO, which crystallizes as large, dark-brown platelets (up to 7 mol. % V_2O_5 and 750°), a crystallization branch for $8PbO \cdot V_2O_5$, which crystallizes as square, dark-brown crystals (up to 16 mol. % V_2O_5 and 732°), and a crystallization branch for $3PbO \cdot V_2O_5$, which crystallizes as hexahedral crystals. No pyrovanadate is found. Mixtures that contain 25 mol. % or more of V_2O_5 solidify as glasses.

Section VII. $\left.\begin{matrix}10 \text{ mol. \% } TiO_2 \\ 90 \text{ mol \% PbO}\end{matrix}\right\}$ + V_2O_5. The following crystallization branches are displayed on the liquidus: lead orthotitanate (4.5 mol % V_2O_5 and 910°), a compound that crystallizes as a dust (up to 21.5 mol.% V_2O_5 and 890°), the branch for this compound exhibiting a maximum at 994°, and a crystallization branch for titanium dioxide, which can be followed up to 45 mol % vanadium pentoxide. Mixtures containing more than 45 mol.% V_2O_5 solidify as glasses. The crystallization branch for titanium dioxide exhibits a maximum at 1110° (Fig. 2).

Section VIII. $\left.\begin{matrix}25 \text{ mol \% } TiO_2 \\ 75 \text{ mol \% PbO}\end{matrix}\right\}$ + V_2O_5. All the mixtures lying along this section have melting points above 1000°. Up to 16 mol.% V_2O_5, $PbTiO_3$ crystallizes as large tetrahedral crystals, while at 20 mol.% V_2O_5 titanium dioxide crystallizes as large needles. The mixture is infusible at 1200° at from 25 to 35 mol.% of vanadium pentoxide, though as the concentration of V_2O_5 is increased still higher, the melting point of the mixture drops until a hyaline phase is formed (at 45 mol.% V_2O_5).

Section X: $\left.\begin{matrix}50 \text{ mol.\% } V_2O_5 \\ 50 \text{ mol.\% PbO}\end{matrix}\right\}$ + $PbTiO_3$.

Section XI: $\left.\begin{matrix}70 \text{ mol.\% } V_2O_5 \\ 30 \text{ mol.\% PbO}\end{matrix}\right\}$ + TiO_2.

A distinctive feature of these sections is the extremely low mutual solubility. At low percentages of lead titanate and titanium dioxide a hyaline phase is formed, from which insoluble titanium dioxide crystallizes out (large needles). The mixture is infusible when the $PbTiO_3$ or the TiO_2 totals more than 25 mol.%.

The data on the fusibility along the sides and the sections are plotted in the triangular fusibility diagram (Figure 3). The areas of crystallization of the following compounds are very clearly evident in the fusibility diagram for the system: (I) PbO; (II) $8PbO \cdot V_2O_5$; (III) $3PbO \cdot V_2O_5$; (IV) Pb_2TiO_4; (V) $PbTiO_3$; (VI) an inner ternary compound, the composition of which may approximate $10PbO \cdot V_2O_5 \cdot TiO_2$; (VII) the crystallization area for titanium dioxide; and (VIII) the area for the hyaline phase.

As we see by the diagram, lead orthotitanate and metatitanate, which are hard to distinguish on the liquidus of the binary system $PbO - TiO_2$, become more distinct when the third component (V_2O_5) is added, possessing their own crystallization areas. The metatitanate ($PbTiO_3$) crystallizes very well as large (exceeding 1 mm) tetrahedral flakes (Sections I, II, and III). The area of crystallization of the metatitanate in the ternary system diagram defines the compositions that may be recommended for the growing of large crystals of lead metatitanate. These findings indicate that we must not start with the stoichiometric proportions of lead monoxide and titanium dioxide if we want to secure crystals of lead metatitanate, but must employ a large excess of lead monoxide (70-75 mol. % PbO and 25 mol. % TiO_2). Lead orthotitanate (Pb_2TiO_4) crystallizes as extremely minute crystals. It is hard to secure large crystals.

Some very satisfactory crystallization has been observed: that of lead monoxide as large brown crystals (Sections I and VI) and that of the compounds $8PbO \cdot V_2O_5$ and $3PbO \cdot V_2O_5$, likewise as large crystals (Sections II, III, and IV).

The absence of crystallization areas for the compounds $2PbO \cdot V_2O_5$ and $PbO \cdot V_2O_5$ is worthy of note. Mixtures consisting of lead monoxide and vanadium pentoxide in proportions corresponding to these compounds form hyaline masses in the presence of titanium dioxide, although the compounds do crystallize when no titanium dioxide is present. Titanium dioxide crystallizes as large needles (Sections I, X, and XI) from the hyaline phase (this region is outlined by a dotted line in Figure 3).

TABLE 6

Section IV: 25 mol. % V_2O_5 + 75 mol. % PbO } + TiO_2

No.	Mol. % TiO_2	Temp. at which crystallization sets in	Remarks
1	0.0	956	
2	3.7	929	
3	6.7	942	Different phase
4	11.7	1000	
5	15.8	1064	Different phase
6	20.0	1132	
7	24.3	1180	
8	28.8	1213	
9	33.3	1232	
10	40.0	Did not fuse	

TABLE 7

Section V: 33.3 mol. % V_2O_5 + 66.7 mol. % PbO } + TiO_2

No.	Mol. % TiO_2	Temp. at which crystallization sets in	Remarks
1	0.0	772	
2	0.5	767	
3	1.5	748	
4	2.3	742	
5	3.3	762	Different phase
6	4	857	
7	5	970	
8	10	1130	
9	15	Did not fuse	
10	20	Did not fuse	

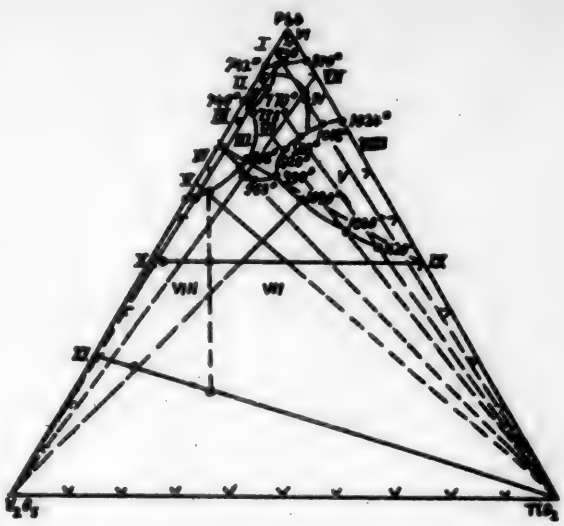

Fig. 3. Fusibility in the $PbO-V_2O_5-TiO_2$ Ternary System.

I) PbO; II) $8PbO \cdot V_2O_5$; III) $3PbO \cdot V_2O_5$; IV) $2PbO \cdot TiO_2$; V) $PbO \cdot TiO_2$; VI) $10PbO \cdot V_2O_5 \cdot TiO_2$; VII) TiO_2; VIII) hyaline phase.

The ternary compound (Figure 3, Area VI) fuses incongruently along Sections I, II, and IV, fusing congruently along Sections III and VII. The section data enabled us to establish its approximate composition as $10PbO \cdot V_2O_5 \cdot TiO_2$ and its melting point as approximately 1000°.

The crystallization area for titanium dioxide occupies more than half the triangle (Figure 3, Area VII). Titanium dioxide crystallizes as large needles in the regions adjacent to the crystallization areas for chemical compounds. These crystals look like those of rutile. The ternary system compositions in the regions adjacent to the crystallization areas for $PbTiO_3$, $10PbO \cdot V_2O_5 \cdot TiO_2$, and $3PbO \cdot V_2O_5$ and in the region of glass formation may be recommended for cultivating the large crystals of titanium dioxide required for research on their dielectric properties.

In conclusion, it must be stated that it is extremely difficult to make a fusibility investigation of this system because of the total opacity of the melts and the high melting point of titanium dioxide.

SUMMARY

1. A partial investigation has been made of the fusibility of the ternary system $PbO-V_2O_5-TiO_2$. The fusibility diagram of the ternary system exhibits the crystallization areas of PbO, Pb_2TiO_4, $PbTiO_3$, $8PbO \cdot V_2O_5$, $3PbO \cdot V_2O_5$, a compound produced for the first time with the approximate composition of $10PbO \cdot V_2O_5 \cdot TiO_2$, and titanium dioxide, as well as a region in which a glass is formed.

TABLE 8

Section VI: 2 mol. % TiO_2 / 98 mol. % PbO + V_2O_5

No.	Mol. % V_2O_5	Temp. at which crystallization sets in	Remarks
1	0.0	881°	
2	5.0	810	
3	7.5	760	Different phase
4	10.0	787	
5	12.5	782	
6	15.0	754	
7	17.5	804	Different phase
8	20.0	890	
9	22.5	935	
10	25.0	948	
11	30.0	901	Glass
12	35.0	732	Glass
13	40.0	716	Glass
14	45.0	710	Glass
15	50.0	682	Glass
16	55.0	644	Glass

TABLE 9

Section VII: 10 mol. % TiO_2 / 90 mol. % PbO + V_2O_5

No.	Mol. % V_2O_5	Temp. at which crystallization sets in	Remarks
1	0.0	878°	
2	2.5	901	
3	5.0	918	
4	7.5	964	Different phase
5	10.0	987	
6	15.0	987	
7	20.0	947	
8	25.0	958	Different phase
9	30.0	1052	
10	35.0	1102	
11	40.0	1090	
12	45.0	1040	
13	50.0	Glass	

TABLE 10

Section VIII: 25 mol. % TiO_2 / 75 mol. % PbO + V_2O_5

No.	Mol. % V_2O_5	Temp. at which crystallization sets in	Remarks
1	10.0	1056°	
2	15.0	1102	
3	20.0	1162	Different phase,
4	25.0	Did not fuse	
5	30.0	Did not fuse	
6	35.0	1200	
7	40.0	1182	
8	45.0	1150	
9	50.0	Glass	

TABLE 11

Section IX: 25 mol. % V_2O_5 / 75 mol. % PbO + $PbTiO_3$

No.	Mol. % $PbTiO_3$	Temp. at which crystallization sets in	Remarks
1	0.0	952°	
2	5.0	935	
3	7.3	930	
4	10.0	924	
5	12.5	924	Different phase
6	15.0	947	
7	17.5	961	
8	20.0	970	
9	22.5	981	
10	25.0	987	
11	27.5	1017	
12	30.0	1052	Different phase, hexahedra
13	32.5	1077	
14	35.0	1089	
15	40.0	1102	
16	45.0	1114	

2. It has been shown that two incongruently fusing compounds ($2PbO \cdot TiO_2$ and $PbO \cdot TiO_2$) are formed in the $PbO - TiO_2$ system. The presence of vanadium pentoxide increases the stability of the metatitanate.

3. The component concentrations that are most suitable for growing large crystals of lead metatitanate and titanium dioxide are outlined.

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ABSORPTION SPECTRA AND DISSOCIATION CONSTANTS OF DIPHENYLTHIOCARBAZONE (DITHIZONE) AND OF ITS INNER COMPLEX SALTS

I. ABSORPTION SPECTRA OF DIPHENYLTHIOCARBAZONE (DITHIZONE) AND ITS EQUILIBRIUM DISTRIBUTION IN A TWO-PHASE SYSTEM

R. E. Chernitskaya

The absorption spectra of many colored organic compounds exhibit a displacement of the maximum on the absorption curve and a change in the intensity of the absorption maximum with the properties of the solvent.

We have investigated the effect of the polar properties of the solvent upon the absorption spectrum of diphenylthiocarbazone (dithizone). As we know, dithizone produces highly colored solutions in organic solvents [1] and is a sensitive reagent for detecting traces of the heavy metals. The absorption curve of a solution of dithizone in carbon tetrachloride exhibits two maxima in the 620 mμ and 450 mμ regions; the absorption maximum of the dithizone ion is located in the 480-490 mμ region. We have secured the absorption spectra of dithizone in benzene, hexane, methyl ethyl ketone, and isoamyl alcohol.

The benzene bore the label "pure, for analysis"; the hexane we used was the fraction boiling in a two-degree interval (67-69°). The methyl ethyl ketone was refined via the bisulfite compound, from which it was isolated by distillation at 79-80°. The isoamyl alcohol was refined by treating it with 5% sulfuric acid to eliminate the pyridine and other organic bases and their homologs. The final product was collected at a boiling point of 128.5-129.5°.

The absorption spectra were secured with a Hilger photoelectric spectrometer for the visible region; they are shown in Fig. 1. The width of the absorption band did not exceed 29 A in the 5000 A region. The values of λ_{1max} and λ_{2max} we secured are listed in Table 1, together with the corresponding values of μ – the dipole moment.

TABLE 1

No.	Solvent	λ_{1max} (mμ)	λ_{2max} (mμ)	$\mu \cdot 10^{18}$ electrostatic units
1	Benzene	600	450	0
2	Hexane	600	435	0.05
3	Methyl ethyl ketone	590	460	2.79
4	Isoamyl alcohol	580	460	1.85
5	Carbon tetrachloride [2]	620	450	0

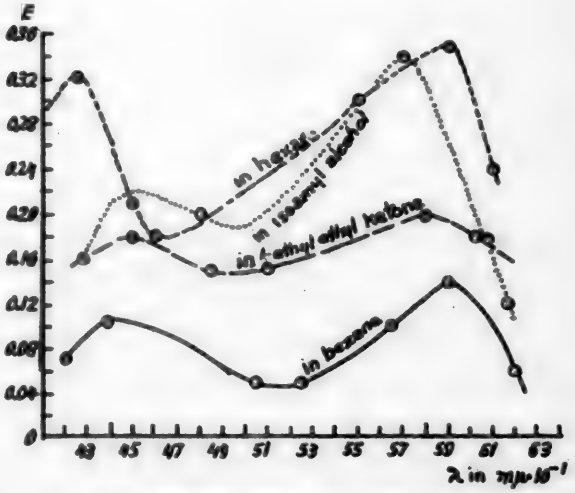

Fig. 1. Absorption spectra of dithizone in various solvents.

As we see in Table 1, the location of the two maxima depends upon the polar properties of the solvent. The wavelength of the first maximum ($\lambda_{1\,max}$), for instance, is displaced toward the shorter wavelengths,

[1] A.A.Pryanishnikov was good enough to communicate to me methods of purifying methyl ethyl ketone and isoamyl alcohol, for which I am deeply grateful.

[2] We have taken the values of $\lambda_{1\,max}$ and $\lambda_{2\,max}$ from the data in the literature.

Moreover, the values we have found for K'_{HD} for solutions of dithizone in isoamyl alcohol and in benzene bear out the hypothesis advanced above that dithizone is a monobasic acid.

SUMMARY

1. An equation has been found that expresses the variation of the position and intensity of the maxima on the curve of spectral absorption for dithizone solutions with the polar properties of the solvent.

2. The equilibrium distribution of dithizone in the isoamyl alcohol—water and the benzene—water system has been measured and calculated. The K'_{HD} has been calculated by the A.Babko and Pilipenko method for solutions of dithizone in the benzene—water and isoamyl alcohol—water systems.

3. A comparison of the values for the equilibrium distribution of dithizone in the two systems led to the conclusion that dithizone is highly soluble in isoamyl alcohol.

4. The hypothesis is advanced that an intermolecular hydrogen bond may be established between the dithizone and isoamyl alcohol molecules.

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THE ABSORPTION SPECTRA AND DISSOCIATION CONSTANTS OF DIPHENYLTHIOCARBAZONE (DITHIZONE) AND OF ITS INNER COMPLEX SALTS

II. ABSORPTION SPECTRA AND INSTABILITY CONSTANTS OF INNER COMPLEX SALTS OF DITHIZONE DISSOLVED IN ISOAMYL ALCOHOL

R. E. Chernitskaya

In our previous paper [1] research on the curve of spectral absorption of dithizone dissolved in isoamyl alcohol and determinations of the equilibrium distribution of dithizone in the isoamyl alcohol—water system served as a basis for our presupposing that dithizone molecules react with molecules of isoamyl alcohol, establishing an intermolecular hydrogen bond between them.

In the present paper we have determined the absorption spectra and instability constants of various inner complex salts of dithizone produced in an isoamyl alcohol solution.[1)]

We have secured the absorption spectra of the inner salts of silver, mercury, copper, zinc, lead, cadmium, and bismuth with the Hilger photoelectric spectrometer (for the visible region). The inner complex salts were prepared as follows: 3 ml of a solution of dithizone in isoamyl alcohol was added to 1.5 ml of a solution of the salt of the respective metallic cation, 1.5 ml of the dithizone solution being used in the case of silver. The mixture was shaken in a separatory funnel for 2 minutes, and then it was allowed to stand for 10 minutes to separate the layers completely. The cell used was 10 mm thick. Isoamyl alcohol served as the control liquid. The concentrations of the salt solutions and of the dithizone solution were 10^{-4} mole per liter.

The absorption spectra of the dithizonates are shown in the figure.

The values of λ_{max} of the absorption curves of the inner complex salts of dithizone are given in Table 1.

TABLE 1

No.	Dithizone, inner complex salt of	λ_{max} in isoamyl alcohol (mμ)	λ_{max} in CCl_4 (mμ)	$\Delta\lambda_{max}$ in isoamyl alcohol (mμ)	$\Delta\lambda_{max}$ in CCl_4 (mμ)
1	Silver	450	460	130	160
2	Zinc	505	535	75	85
3	Cadmium . . .	500	510	80	110
4	Mercury	490	530	90	90
5	Lead	505	525	75	95
6	Copper	500	510	80	110
7	Bismuth	495	500	85	120

The λ_{max} of the absorption spectrum of dithizone in isoamyl alcohol is 580 mμ. The λ_{max} of the absorption spectrum of dithizone dissolved in CCl_4 is 620 mμ.

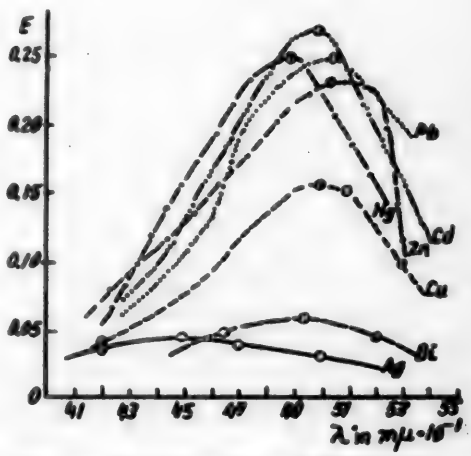

Figure. Absorption spectra of dithizonates.

1) The laboratory assistant V. G. Tararashkina participated in this research

The data listed in Table 1 indicate that the shift of the λ_{max} (toward the ultra-violet) of the inner complex salt of dithizone in isoamyl alcohol with respect to the λ_{max} of the solution of pure dithizone ($\Delta\lambda_{max}$) in isoamyl alcohol is less than in the carbon tetrachloride solution.

We have determined the instability constants of the inner complex salts of silver, copper, zinc, lead, and cadmium dithizonates, prepared in isoamyl alcohol.

We measured the instability constants by the method described in the papers of A. Babko and Pilipenko [2,3], using a Hilger absorptiometer with the appropriate light filters. The cell was 10 mm thick. Isoamyl alcohol was used as the control liquid.

The concentrations of the dithizone solution in isoamyl alcohol and of the original metal salt were about 10^{-4} mole per liter.

Our findings are set forth in Tables 2-7.

TABLE 2

Instability Constant of Silver Dithizonate Dissolved in Isoamyl Alcohol

Initial concentrations: Ag^{+} in water: $9.27 \cdot 10^{-4}$ mole/liter; dithizone in isoamyl alcohol: $8.59 \cdot 10^{-4}$ mole/liter

No.	pH	Millimoles of silver dithizonate found, P_0	Equilibrium concentrations, moles/liter			K'_{AgD}
			Ag^{+} in water	$C_{MC} \cdot 10^4$ in isoamyl alcohol	$C_{KC} \cdot 10^4$ in isoamyl alcohol	
1	5.16	$0.74 \cdot 10^{-4}$	$9.205 \cdot 10^{-4}$	8.096	0.247	$0.18 \cdot 10^{-9}$
2	5.19	$1.25 \cdot 10^{-4}$	$9.161 \cdot 10^{-4}$	7.76	0.417	$0.09 \cdot 10^{-9}$
3	5.22	$0.71 \cdot 10^{-4}$	$9.208 \cdot 10^{-4}$	8.12	0.233	$0.17 \cdot 10^{-9}$
4	5.06	$1.4 \cdot 10^{-4}$	$9.148 \cdot 10^{-4}$	7.66	0.466	$0.12 \cdot 10^{-9}$
5	5.16	$4.63 \cdot 10^{-4}$	$9.229 \cdot 10^{-4}$	8.28	0.154	$0.31 \cdot 10^{-9}$
6	5.36	$4.63 \cdot 10^{-4}$	$9.228 \cdot 10^{-4}$	8.28	0.154	$0.19 \cdot 10^{-9}$
7	4.88	$1.09 \cdot 10^{-4}$	$9.175 \cdot 10^{-4}$	7.86	0.363	$0.23 \cdot 10^{-9}$
8	5.48	$1.06 \cdot 10^{-4}$	$9.177 \cdot 10^{-4}$	7.88	0.354	$0.06 \cdot 10^{-9}$
9	5.48	$0.7 \cdot 10^{-4}$	$9.209 \cdot 10^{-4}$	8.12	0.233	$0.01 \cdot 10^{-9}$
				Average		$0.15 \cdot 10^{-9}$

TABLE 3

Instability Constant of Zinc Dithizonate Dissolved in Isoamyl Alcohol.
Initial concentrations: Zn^{++} in water: $1.871 \cdot 10^{-3}$ mole/liter; dithizone in isoamyl alcohol: $2.24 \cdot 10^{-4}$ mole/liter

No.	pH	Millimoles of zinc dithizonate found, P_0	Equilibrium concentrations, moles liter			K'_{ZnD_2}
			Zn^{++} in water	$C_{MC} \cdot 10^4$ in isoamyl alcohol	$C_{KC} \cdot 10^4$ in isoamyl alcohol	
1	3.6	$6.173 \cdot 10^{-5}$	$1.135 \cdot 10^{-3}$	1.82846	0.20576	$0.29 \cdot 10^{-22}$
2	3.85	$11.11 \cdot 10^{-5}$	$0.905 \cdot 10^{-5}$	1.499	0.3703	$0.28 \cdot 10^{-22}$
3	4.56	$12.44 \cdot 10^{-5}$	$0.789 \cdot 10^{-5}$	1.4106	0.4146	$0.9 \cdot 10^{-22}$
					Average	$0.49 \cdot 10^{-22}$

We used the computational method and the notation given in the paper by A.Babko and Pilipenko: C_{KC} denotes the concentration of the inner complex dithizone salt in the isoamyl alcohol phase; C_{MC} the concentration of dithizone in the isoamyl alcohol; P_0 the amount of the inner complex salt, expressed in millimoles and calculated from the calibration curve (optical density vs. millimoles of the dithizonate); and K' was calculated from the equation $K' = \frac{Me^{++}[D']^2}{C_{KC}}$, where Me^{++} is the equilibrium concentration of the cation of the given metal in water, D' is the concentration of the anion of the dithizone molecule, which we had previously found [1] from the equation $K'_{HD} = \frac{[H][D']}{[HD]}$.

TABLE 4

Instability Constant of Cadmium Dithizonate Dissolved in Isoamyl Alcohol.

Initial concentrations: Cd^{++} in water: $2.965 \cdot 10^{-5}$ mole/liter; dithizone in isoamyl alcohol: $3.125 \cdot 10^{-4}$ mole/liter.

No.	pH	Millimoles of cadmium dithizonate found, P_0	Equilibrium concentrations, moles/liter			K'_{CdD_2}
			Cd^{++} in water	$C_{MC} \cdot 10^4$ in isoamyl alcohol	$C_{KC} \cdot 10^4$ in isoamyl alcohol	
1	3.6	$1.335 \cdot 10^{-4}$	$1.804 \cdot 10^{-5}$	2.235	0.445	$0.32 \cdot 10^{-22}$
2	4.18	$2.468 \cdot 10^{-4}$	$1.688 \cdot 10^{-5}$	2.087	0.489	$0.36 \cdot 10^{-22}$
3	3.2	$0.7563 \cdot 10^{-4}$	$2.307 \cdot 10^{-5}$	2.621	0.2521	$0.41 \cdot 10^{-22}$
4	3.06	$1.2267 \cdot 10^{-4}$	$2.769 \cdot 10^{-5}$	2.974	0.0756	$0.43 \cdot 10^{-22}$
				Average		$0.38 \cdot 10^{-22}$

TABLE 5

Instability Constant of Mercury Dithizonate Dissolved in Isoamyl Alcohol.

Initial concentrations: Hg^{++} in water: $4.98 \cdot 10^{-4}$ mole/liter; dithizone in isoamyl alcohol: $6.25 \cdot 10^{-4}$ mole/liter.[1)]

No.	pH	Millimoles of mercury dithizonate found, P_0	Equilibrium concentrations, moles/liter			K'_{HgD_2}
			Hg^{++} in water	$C_{MC} \cdot 10^4$ in isoamyl alcohol	$C_{KC} \cdot 10^4$ in isoamyl alcohol	
1	4.93	$2.49 \cdot 10^{-4}$	$4.763 \cdot 10^{-4}$	4.59	0.83	$0.71 \cdot 10^{-18}$
2	4.89	$3.16 \cdot 10^{-4}$	$4.531 \cdot 10^{-4}$	2.81	1.72	$0.1 \cdot 10^{-18}$
3	4.79	$3.69 \cdot 10^{-4}$	$4.659 \cdot 10^{-4}$	3.79	1.23	$0.16 \cdot 10^{-18}$
4	4.6	$2.49 \cdot 10^{-4}$	$4.769 \cdot 10^{-4}$	4.59	0.83	$0.16 \cdot 10^{-18}$
5	4.5	$4.2 \cdot 10^{-4}$	$4.614 \cdot 10^{-4}$	3.45	1.4	$0.03 \cdot 10^{-18}$
6	4.93	$4.492 \cdot 10^{-4}$	$4.768 \cdot 10^{-4}$	3.34	0.83	$0.37 \cdot 10^{-18}$
7	4.86	$1.236 \cdot 10^{-4}$	$4.876 \cdot 10^{-4}$	4.2	0.42	$0.87 \cdot 10^{-18}$
				Average		$0.39 \cdot 10^{-18}$

Notes to Tables 2-5: 1) The volume of the aqueous phase was 11.5 ml in all the tests.
2) The volume of the nonaqueous phase was 3 ml in all the tests.

The values we found for the constant $K' = KP$, where K was the true instability constant, and P was the distribution coefficient of the inner complex salt in the two phases. By taking the value of P to be approximately the same for any given solvent, we were able, however, to compare the K' as true instability constants.

We made a comparison of the values of the instability constant K' we had secured for the specified inner complex salts of dithizone with the values of λ_{max} listed in Table 1 above and with the values of $\epsilon\lambda_{max}$ that we had calculated for the respective inner complex salts. These findings are listed in Table 8.

Table 8 indicates that as the complex salt's instability constant rises, the shift of λ_{max} toward the ultraviolet region is increased, while the intensity of λ_{max} diminishes.

We endeavored to determine the composition of the silver dithizonate complex salt dissolved in isoamyl alcohol by the Job method. We equipped an ISP-51 spectrograph to measure absorption spectra: the light source was a 100-watt bulb with a straight wolfram filament, which yielded a continuous spectrum in the visible region, the measurement cell being a brass tube (Bailey) gilded on the inside, with a screw thread that made it possible to read the layer thicknesses to 0.01 mm.

The wavelength standard was the spectrum of the iron arc. Isoortho photographic plates with a speed of 400 HD were used.

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1) The initial concentrations in Tests 6 and 7 were as follows: Hg^{++} in water: $4.985 \cdot 10^{-4}$ mole/liter; and dithizone in isoamyl alcohol: $5.039 \cdot 10^{-4}$ mole/liter.

TABLE 6

Instability Constant of Lead Dithizonate Dissolved in Isoamyl Alcohol

Initial concentrations: Pb^{++} in water $-9\cdot10^{-4}$ mole/liter; dithizone in isoamyl alcohol: $3.8\cdot10^{-4}$ mole/liter.

No.	pH	Millimoles of lead dithizonate found, P_θ	Equilibrium concentration, mole/liter			K'_{PbD_2}
			Pb^{++} in water	$C_{MC}\cdot10^4$ in isoamyl alcohol	$C_{KC}\cdot10^4$ in isoamyl alcohol	
1	3.01	$2.896\cdot10^{-4}$	$8.75\cdot10^{-4}$	6.069	0.9653	$0.35\cdot10^{-21}$
2	3.21	$4.967\cdot10^{-4}$	$8.57\cdot10^{-4}$	4.689	1.6556	$0.3\cdot10^{-21}$
3	3.8	$9.653\cdot10^{-4}$	$8.16\cdot10^{-4}$	1.565	3.2176	$0.317\cdot10^{-21}$
4	2.98	$1.931\cdot10^{-4}$	$8.83\cdot10^{-4}$	6.712	0.6433	$0.56\cdot10^{-21}$
				Average.....		$0.38\cdot10^{-21}$

TABLE 7

Instability Constant of Copper Dithizonate Dissolved in Isoamyl Alcohol

Initial concentrations: Cu^{++} in water: $1.58\cdot10^{-4}$ mole/liter; dithizone in isoamyl alcohol: $8.594\cdot10^{-4}$ mole/liter

No.	pH	Millimoles of copper dithizonate found, P_θ	Equilibrium concentration, moles per liter			K'_{CuD_2}
			Cu^{++} in water	$C_{MC}\cdot10^4$ in isoamyl alcohol	$C_{KC}\cdot10^4$ in isoamyl alcohol	
1	4.13	$2.523\cdot10^{-4}$	$1.361\cdot10^{-4}$	6.912	0.841	$1.6\cdot10^{-20}$
2	4.0	$2.203\cdot10^{-4}$	$1.388\cdot10^{-4}$	7.126	0.734	$1.23\cdot10^{-20}$
3	3.85	$4.963\cdot10^{-4}$	$1.236\cdot10^{-4}$	5.954	1.32	$0.13\cdot10^{-20}$
4	3.6	$3.487\cdot10^{-4}$	$1.276\cdot10^{-4}$	6.269	1.162	$0.55\cdot10^{-20}$
5	3.4	$2.305\cdot10^{-4}$	$1.379\cdot10^{-4}$	7.057	0.768	$0.46\cdot10^{-20}$
				Average.....		$0.71\cdot10^{-20}$

TABLE 8

No.	Inner complex, dithizone salt of	K'	λ-max (mμ)	$\varepsilon\lambda$max
1	Silver	$0.15\cdot10^{-9}$	450	110
2	Mercury	$0.39\cdot10^{-18}$	490	700
3	Zinc	$0.49\cdot10^{-22}$	505	600
4	Lead	$3.8\cdot10^{-22}$	505	710
5	Copper	$0.71\cdot10^{-20}$	500	600
6	Cadmium	$0.38\cdot10^{-22}$	510	800

The blackening marks were produced by means of a step-by-step platinum clearing agent.

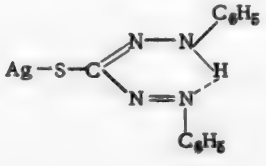
The absorption spectra were photographed through a solution of the inner complex salt silver dithizonate, the ratios between the ml of the initial silver salt solution and the solution of dithizone in isoamyl alcohol being as follows (both solutions having the same concentration: 10^{-4} mole per liter).

Ml of the silver salt solution	Ml of the dithizone solution
0.5	2.5
1.5	1.5
2	1.0
2.5	0.5

The blackening marks were photographed on the same plate as the silver dithizonate solutions. The solution pH was 6.8. After the photometric readings had been taken with a MF-2 microphotometer, the degree of blackening of the plate was evaluated at two points in the spectrum: 560 mμ and 460 mμ. We used a somewhat simplified method of estimating the degree of blackening, this simplification consisting in estimating the degree of blackening at the point of absorption via the points of equal blackening for the control liquid as photographed with the step-by-step clearing agent and for the test spectrum, instead of plotting a blackening curve for the given wavelength.

Taking photometric readings of a large number of photographic plates bearing the spectra of the inner complex silver salt, photographed at the ratios indicated above we found that the difference in intensity of blackening was a maximum at 580 mμ (the λ_{max} for pure dithizone) and at 460 mμ (the λmax for silver dithizonate) at a 1:1 molar ratio of the silver salt solution for the dithizone solution.

These findings led us to this formula for silver dithizonate: AgD (where D is the dithizonate ion), from which it follows that the structure of silver dithizonate may be as follows:



The intramolecular hydrogen bond within the dithizone ion itself, together with the possible interaction of the dithizone ion [illegible] with the molecules of isoamyl alcohol, make our assumption of the silver–sulfur bond even more probable.

The order of magnitude of our values for the instability constant of silver dithizonate approaches that of the instability constant for the coordination compound of silver and hydrogen sulfide recently obtained by Treadwell and Hepenstrick [4].

SUMMARY

1. The λ_{max} of the absorption spectra of the inner complex salts silver, mercury, lead, copper, zinc, cadmium, and bismuth dithizonates, dissolved in isoamyl alcohol, have been measured and compared.

2. The Babko and Pilipenko method has been used to determine the instability constants of silver, mercury, copper, zinc, lead, and bismuth dithizonates, and these constants have been compared.

3. The relationship between the λ_{max} of dithizonates dissolved in isoamyl alcohol and their instability constants has been established.

4. The method of photographic spectrophotometry has been employed to determine the composition of AgD, and a suggestion is put forward concerning the possible structure of this inner complex salt.

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RESEARCH ON ACID CATALYSTS

I. THE KINETICS AND REACTION MECHANISM OF FORMALDEHYDE IN AQUEOUS ACID SOLUTIONS

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The conversion of aqueous solutions of formaldehyde to methanol and formic acid, which is frequently considered to be an oxidative-reduction reaction, may be effected in the presence of an alkali (as Cannizzaro [1], Meyer [2], Raikov and Reshtanov [3], and other research workers have observed in the case of other aldehydes) as well as in acid media.

As far back as 1883 Tishchenko [4] heated formaldehyde for a long time in sealed tubes together with strong hydrohalic acids and obtained formic acid and methyl halides. He later found that a reaction with 10% hydrochloric acid yielded formic acid and methanol itself, the reaction not proceeding to completion, part of the formaldehyde being recovered untreated even after heating to 100° for several weeks [5]. V.E. Tishchenko is also the author of the most reasonable hypothesis to explain this reaction. In 1906, in his classical paper "On the action of aluminum alcoholates upon aldehydes" [6], Tishchenko cites the following equations, after a critical review of the numerous hypotheses put forward by various authors:

in which the initial conversion product is an ester, methyl formate. But up to the present time no data have been cited in the literature to confirm this hypothesis. Nor have any papers been published on the kinetics of this reaction in acid media. The present paper fills this gap to a certain extent.

Chemistry of the Reaction

To check the composition of the formaldehyde conversion products, a special experiment was run in a stainless steel reactor, consisting of a steel tube fitted with a jacket in which a xylene fraction was boiled, thus ensuring a temperature of 140° within the reactor.

Into the reactor we charged 458 g of an aqueous solution containing 29.0% formaldehyde (introduced as paraform) and 12% chemically pure sulfuric acid. The mixture was heated for 4 hours and then poured out and analyzed, the formaldehyde being determined iodometrically [7]. The total acidity was determined by rapid titration with 0.1 N alkali, the amount of formic acid produced being found from the difference between the titrations of the initial and final solutions. The presence of formic acid was also confirmed qualitatively by the formation of calomel when the respective fractions were treated with mercuric chloride. Then the liquid was neutralized with an excess of ammonia, which also bound a substantial proportion of the formaldehyde as hexamethylenetetramine, and then fractionated into a laboratory rectifying column with an efficiency of 60 theoretical trays under operating conditions.

The characteristics of the principal fractions are given in Table 1, which shows that they are fairly pure methyl formate, methylal, and methanol.

The composition of the small intermediate fractions, which were binary mixtures, was determined by chemical analysis and by their refractive indexes. These findings are given in Table 2 as a material balance. The balance indicates that methylal is produced as follows:

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[1]) S.P. Rabinovich assisted in the experimental work.

TABLE 1

Characteristics of the Principal Fractions Collected During the Fractionation of the Reaction Products Into a Rectifying Column

		Fractions		
		Methyl formate	Methylal (azeotropic)	Methanol
Boiling point	present research	31.5-32.0°	40.7-41.5°	63.5-64.0°
	data in the literature	31.8°[8]	42.05° [20]	64.5° [8]
Specific gravity d_4^{20}	present research	0.9677	0.8651	0.7907
	data in the literature	0.975	0.862 [1)]	0.792
Refractive index n_D^{20}	present research	1.3435	1.3519	1.3292
	data in the literature	1.344	1.3534 [1)]	1.329
Wt. % of the principal component, by chemical analysis present research		98.0 [9]	not measured	99.5 [7]

$$CH_2O + 2CH_3OH \longrightarrow CH_2(OCH_3)_2 + H_2O,$$

in addition to the major reactions given above.

Furthermore, comparison of the quantities of free formic acid and methanol (both free and combined as methylal) indicates that they are equivalent within the limits of experimental error. Thus, 0.66 mole of HCOOH was found in the reaction product, while the amount of methanol totaled: 0.492 + 2·0.054 = 0.60 mole.

The slight discrepancy between these two figures is attributable, first to a certain exaggeration of the percentage of formic acid found, due to partial saponification of the methyl formate when titrated with alkali, and second to losses of the highly volatile methylal.

TABLE 2

Chemical Balance of the Conversion of Formaldehyde at 140° with 12% H_2SO_4

Fed in	Quantity		Produced	Quantity		CH_2O consumed (moles)
	Grams	Moles		Grams	Moles	
CH_2O	133	4.43	$HCOOCH_3$.....	10.90	0.182	0.364
Including converted			HCOOH.....	30.35	0.660	0.660
			CH_3OH.....	15.70	0.492	0.492
CH_2O.....	60.3	2.01	$CH_2(OCH_3)_2$....	4.13	0.054	0.162
Water.....	294.0	16.35	Water.....	283.0	15.70	—
			CH_2O losses...	—	—	0.332
					Total....	2.01

Even higher losses are to be counted on in the case of methyl formate, the boiling point of which (32°) is close to room temperature. Hence, much of the loss of formaldehyde in the material balance may be due to the $HCOOCH_3$, the quantity of which is correspondingly low in Table 1. Moreover, some of the formaldehyde may be converted into paraformaldehyde, which is not determined in the usual iodometric analysis for formaldehyde.

Nevertheless, the relationship between the quantities of methyl formate, methanol, and formic acid we have found enables us to reach certain conclusions when these figures are contrasted with the equilibrium concentrations of the conversion products.

Unfortunately, we have no data on the equilibrium constant of the hydrolysis of methyl formate at the temperature specified for our experiment. Euler [10] states, however, that the equilibrium concentrations of the constituents remain practically unchanged from 0 to 60° in the hydrolysis of esters. Moreover, Schultz [11] checked Euler's data for ethyl formate and got practically the same value for the equilibrium constant at 100° that Euler had found for 50° (0.385 as against Euler's value of 0.36).

[1)] The literature data are for pure (anhydrous) methylal.

We were thus able to employ Schultz's experimental findings [11] directly to calculate the equilibrium concentration of methyl formate under our experimental conditions, i.e., at 140°. Schultz measured the equilibrium constant of the system:

$$CH_3OOCH + H_2O \rightleftarrows CH_3OH + HCOOH$$

fairly accurately at 100 ± 2° throughout a wide range of water concentrations. In our high dilution, the value of $\underline{K} = 0.24$, so that the equilibrium molar quantity of methyl formate ought to be, according to Table 2:

$$[CH_3OOCH] = \frac{[CH_3OH]\,[HCOOH]}{K[H_2O]} = \frac{0.492 \cdot 0.660}{0.24 \cdot 15.7} = 0.086 \text{ g.}$$

The experimental figure of 0.182 mole is more than twice as high as the equilibrium molar concentration of methyl formate, which far exceeds any possible experimental error. And when we remember that the CH_3OOCH concentration determined analytically was evidently too low, the excess over the equilibrium concentration of methyl formate is no longer subject to any doubt.

Hence, the conversion of formaldehyde into methanol and formic acid must involve the intermediate formation of methyl formate, which is then hydrolyzed. If this were not so, the concentration of methyl formate in the reaction products could not be higher than the equilibrium concentration.

Thus, the hypothesis advanced by V E Tishchenko nearly half a century ago has been directly corroborated by experiment. This cuts the ground out from the formal concept referred to above that the Cannizzaro–Tishchenko reaction is an "oxidative-reduction" reaction.

Preliminary Kinetic Analysis

Two two-stage sets of reactions may be adduced as the most likely one for a Cannizzaro–Tishchenko reaction in an acid medium.

The first stage, which is common to both sets, must be the formation of a reaction coordination compound as follows:

$$A.\ CH_2(OH)_2 + H_2SO_4 \rightleftarrows HOCH_2OH \cdot H_2SO_4$$

which can then react with a similar coordination compound as follows:

$$B_1.\ 2HOCH_2OH \cdot H_2SO_4 \longrightarrow CH_3OOCH + 2H_2O + 2H_2SO_4$$

or with a free molecule of methylene glycol:

$$B_2.\ HOCH_2OH \cdot H_2SO_4 + CH_2(OH)_2 \longrightarrow CH_3OOCH + 2H_2O + H_2SO_4.$$

In both cases we have employed the methylene glycol form rather than the aldehydic form for the formaldehyde dissolved in water. Several papers have demonstrated by cryoscopic determinations of molecular weights, and especially, spectroscopically, that the aldehyde form is practically absent in aqueous solutions [12]. For example, Schou [13] has found that the spectra of formaldehyde dissolved in hexane exhibit the characteristic frequencies of the carbonyl group $H_2C = O$, whereas such anhydrated molecules constitute less than 0.09% of the total of formaldehyde molecules in aqueous solutions.

However, even the fully hydrated form is actually methylene glycol only in weak formaldehyde solutions (2% and less), since an equilibrium reaction involving the polymerization of the methylene glycol monomer into its polymers is set up in the solution. According to Auerbach and Barschal [14], the principal polymerization is the formation of the trimer as follows:

$$3CH_2(OH)_2 \rightleftarrows HOCH_2OCH_2OCH_2OH + 2H_2O.$$

The equilibrium of this reaction at formaldehyde concentrations up to 30% is satisfactorily described by the equation:

$$K = \frac{[CH_2(OH)_2]^3}{[HO(CH_2O)_3H][H_2O]^2} = 0.026,$$

where $\underline{K} = 0.026$ is the equilibrium constant at 20°.

The equilibrium concentrations of the monomer – methylene glycol – calculated for aqueous solutions at 20° are given in Table 3.

TABLE 3

Concentrations of Methylene Glycol in Mixtures with Trioxymethylene Glycol in Aqueous Solutions at 20°

Per cent concentration of formaldehyde in water	2.4	5.9	11.2	21.1	28.2	33.8
Per cent of formaldehyde as methylene glycol.....	98	87	72	53	41	33

The figures in Table 3 indicate that the concentration of the monomer is fairly high at 20° for all the concentrations of formaldehyde solutions that are attainable in practice. At higher temperatures the state of equilibrium must be shifted toward dissociation, as is the case in other polymerization reactions. We may therefore assume, as a first approximation, that at the temperatures employed in the present research most of the formaldehyde occurs in the reaction liquid as methylene glycol, as indicated in the reactions set forth above.

As for the structure of the reaction coordination compound referred to above, this problem is of no account for our further discussion. What is most likely, however, is the formation of an oxonium compound, as follows:

$$[HOCH_2-\underset{\displaystyle H}{\underset{|}{O}}-H^+]HSO_4^-$$

The possibility that such compounds may be formed when sulfuric acid reacts with diethyl ether has been demonstrated by the researches of V. V. Chelintsev, who secured the following coordination compounds:

$$(C_2H_5)_2O \cdot H_2SO_4 \quad \text{and} \quad 2(C_2H_5)_2O \cdot H_2SO_4$$

as far back as 1914 and determined their heats of formation [15]. Subsequently, the actual existence of these coordination compounds was convincingly proved by Usanovich, Sabinina, and Zavarikhina [16], who made a comprehensive study of the physicochemical properties of the ether + sulfuric acid and water + sulfuric acid systems.

Kendall and his co-workers established that oxonium coordination compounds are formed by sulfuric acid with alcohols, using as their examples the higher phenols: $\underline{o}\text{-}(CH_3)_2C_6H_3OH \cdot H_2SO_4$ and $\underline{p}\text{-}(CH_3)_2C_6H_3OH \cdot H_2SO_4$ [17].

We still have no corresponding data in the literature for the aliphatic alcohols, though the systematic researches of V.V.Chelintsev on the heat involved in the formation of coordination compounds of various oxygen-containing compounds with organo-magnesium alcoholates enable us to reach certain conclusions in this respect as well.

V. V. Chelintsev's findings [18] on the heats of formation of coordination compounds of the initial molecules of some alcohols and diethyl ether with C_2H_5OMgI and sulfuric acid are given in Table 4.

TABLE 4

Heats of Formation of Some Oxonium Compounds According to V. V. Chelintsev [18]

Compound	Central group in the coordination compound	Heat evolved by the addition of the initial molecule, cal·mole
Methanol.....	C_2H_5OMgI	11.60
Ethyl alcohol.....		12.78
Isopropyl alcohol...		8.88
Phenol.....		5.06
Diethyl ether.....	C_2H_5OMgI	5.05
Diethyl ether.....	H_2SO_4	6.87

Inspection of Table 4 indicates that the heat evolved by addition of C_2H_5OMgI to diethyl ether is close to that involved in the addition of sulfuric acid. By analogy it may be assumed that the heat of formation of an oxonium coordination compound of primary alcohols and sulfuric acid will likewise approach the heat of formation of a coordination compound containing C_2H_5OMgI. This thermal effect for the primary alcohols is more than twice that for a coordination compound with the ether.

Hence, strong bonds may be established by the higher valencies of the oxygen in the hydroxyl group in the alcohols, these bonds producing a fundamental change in the electronic structure of the $CH_2(OH)_2$ molecule in an oxonium coordination compound, and this is responsible for the substantial activation of the methylene group. This makes the latter able to enter into a reaction either with another similarly activated molecule of the oxonium coordination compound or with an ordinary methylene glycol molecule, these two alternatives constituting the two reaction mechanisms set forth above.

The ionic nature of the reaction involved in the formation of the oxonium coordination compound in an aqueous solution leads us to conclude that methylene glycol reacts extremely rapidly with sulfuric acid. We therefore assume that the first stage common to both sets of reactions proceeds until equilibrium is practically achieved, as defined by the equation:

$$K_C = \frac{[CH_2(OH)_2 \cdot H_2SO_4]}{[CH_2(OH)_2][H_2SO_4]} = \frac{z}{(a - z)(b - z)} , \quad (1)$$

where K_C is the equilibrium constant; z is the concentration of the coordination compound; and a and b are the total concentrations of methylene glycol and sulfuric acid, respectively. The symbols in brackets are the respective equilibrium concentrations of the reaction components.

But when the concentration of the oxonium coordination compound is not very high, compared to the total amount of methylene glycol present (which actually is the case, as will be shown later), Equation (1) may be simplified as follows:

$$K_C = \frac{z}{a(b - z)} , \quad (2)$$

whence the concentration of the reaction coordination compound is:

$$z = \frac{ab}{a + \frac{1}{K_C}} , \quad (3)$$

Equation (3) may be used to set up the kinetic equation for both of the postulated sets of reactions. Starting with the stipulated assumption that the controlling reaction rates will be those of the second process stages, we get the corresponding equations.

Mechanism I yields the equation:

$$\frac{dx}{d\tau} = k'' [CH_2(OH)_2 \cdot H_2SO_4]^2 = k'' \frac{a^2 b^2}{\left(a + \frac{1}{K_C}\right)^2} , \quad (4)$$

where k'' is the constant of action of B_1.

Introducing the following notation: a_0 for the initial amount of methylene glycol per unit of solution, $C_{H_2SO_4}$ for the concentration of sulfuric acid, x for the amount of methylene glycol converted in time τ, and $y = x/a_0$ for the proportion of the methylene glycol converted in time τ, we obtain the following differential equation:

$$a_0 \frac{dy}{d\tau} = k'' C^2_{H_2SO_4} \frac{(1 - y)^2}{\left(1 - y + \frac{1}{a_0 K_C}\right)^2} , \quad (4a)$$

integration of which yields the general form of equation for the constant of action k'':

$$k'' = \frac{1}{C^2_{H_2SO_4} \tau} \left[a_0 y + \frac{4.6}{K_C} \log \frac{1}{1 - y} + \frac{y}{a_0 K_C^2 (1 - y)} \right] . \quad (5)$$

Mechanism II yields the initial equation:

$$\frac{dx}{d\tau} = k' [CH_2(OH)_2 \cdot H_2SO_4][CH_2(OH)_2] = k' \frac{a^2 b}{a + \frac{1}{K_C}} \quad (6)$$

whence, by analogy with the preceding derivation, we secure

$$\frac{dy}{d\tau} = k' C_{H_2SO_4} \frac{(1 - y)^2}{1 - y + \frac{1}{a_0 K_C}} \quad (6a)$$

integration of which yields the general equation

$$k' = \frac{1}{C_{H_2SO_4}\tau}\left[2.3 \log \frac{1}{1-y} + \frac{y}{a_0 K_C (1-y)}\right]. \quad (7)$$

Inspection of Equations (5) and (7) yields the following conclusions.

1. In both cases the reaction rate may be monomolecular at high values of the equilibrium constant K_C and bimolecular at extremely low values of K_C. This conclusion follows from the presence in Equations (5) and (7) of terms, the last of which correspond to an expression for a second-order reaction, while the preceding ones correspond to that for a first-order reaction. The ratio between these two terms will vary widely with the value of K_C, and in the extreme cases the terms that become extremely small may be neglected.

2. When the reaction follows the patern of Mechanism I, as specified by Equation (5), the rate at which the formaldehyde is converted must be proportional to the square of the sulfuric acid concentration, whereas when the reaction is of the Mechanism II type, as specified by Equation (7), the rate must be proportional to the first power of the sulfuric acid concentration. In the intermediate case, i.e., when the reaction is mixed, with both types present at the same time, we must have, formally speaking, a fractional order of reaction with respect to acid.

Procedure Used for Kinetic Measurements

The tests were run in sealed glass ampoules, with a capacity of approximately 10 ml, into which a solution of pure paraform in distilled water was introduced together with a measured quantity of chemically pure sulfuric acid.

In preliminary tests, the ampoules were heated on water or glycerol baths, the temperature of which differed from the given temperature by 3 to 5° in individual instances In the precise kinetic experiments we employed an ultrathermostat in which the temperature fluctuations did not exceed 0.2°C.

The ampoules were taken out of the thermostat at given intervals of time, quickly cooled, and their contents analyzed.

The formaldehyde was determined iodometrically [7], the formic acid being determined by the difference between the titrations of the reacted and initial solutions.

Kinetic Data and Their Evaluation

The results of our preliminary tests, made with less precise temperature control, are given in Table 5.

All the converted formaldehyde is listed in Column 5, Column 6 gives the amount of formaldehyde converted into formic acid. Comparison of these figures indicates that much of the methyl formate formed initially is subjected to very deep hydrolysis in all cases, as was observed in the balance test described by us.

Since it is difficult to use the derived general Equations (5) and (7) directly because of the absence of the values of the constant K_C, we employed simpler expressions in working up the experimental data of Table 5, which describe the special cases referred to in the preliminary kinetic analysis of the greatest and smallest values of the equilibrium constant, i.e., for $K_C \gg 1$.

Mechanism I: $$k_1' = \frac{a_0 y}{C_{H_2SO_4}\tau}; \quad (8)$$

Mechanism II: $$k_1' = \frac{2.3}{C_{H_2SO_4}\tau} \log \frac{1}{1-y} \quad (9)$$

for $K_C \ll 1$.

Mechanism I: $$k_2' = \frac{y}{C^2_{H_2SO_4}\, a_0 \tau (1-y)} \quad (10)$$

Mechanism II: $$k_2' = \frac{y}{C_{H_2SO_4}\, a_0 \tau (1-y)} \quad (11)$$

where $C_{H_2SO_4}$ is the concentration of sulfuric acid in moles per 100 grams; a_0 is the initial concentration of formaldehyde in moles per 100 grams; τ is the time in hours. The values of the velocity constants computed from these equations (cf. Table 5) indicate that Equations (8) and (9), dealing with $K_C \gg 1$, are entirely unsuitable to describe the reaction kinetics, inasmuch as the values of the constant rise sharply with increasing initial

TABLE 5

Kinetics of the Conversion of Formaldehyde in Aqueous Acid Solutions (Preliminary Tests)

No. of determination	Temperature	Time, hours (τ)	Concentration, wt. %		Formaldehyde consumed, moles/100 g		Converted proportion of $CH_2(OH)_2$, y	Constants of action				
			Acid in terms of H_2SO_4	CH_2O	Total $CH_2(OH)_2$	In terms of HCOOH		Monomolecular		Bimolecular		Mixed
								$k_1' \cdot 10$, Equation (8)	$k_1'' \cdot 10$, Equation (9)	$k_2''' \cdot 10$, Equation (10)	$k_2'' \cdot 10$, Equation (11)	$k_2''' \cdot 10$, Equation (14)
1		2	3	4	5	6	7	8	9	10	11	12
1	100°	0	6.35	14.1	–	–	–	–	–	–	–	–
		20	6.70	13.9	0.006	0.014	0.013	0.7	1.1	3.3	2.2	0.6
		40	6.95	13.3	0.026	0.024	0.055	1.5	2.1	7.3	4.7	1.4
		80	7.25	12.9	0.040	0.036	0.085	1.2	1.8	5.8	3.8	1.1
							Average	1.0	1.7	5.5	3.6	1.0
2	100°	0	6.25	28.5	–	–	–	–	–	–	–	–
		20	6.50	27.5	0.032	0.010	0.034	3.9	2.7	4.5	2.9	0.9
		40	7.75	26.1	0.080	0.080	0.084	4.9	3.4	5.9	3.7	1.2
		80	8.05	24.9	0.120	0.072	0.126	3.7	2.6	4.6	3.0	0.9
							Average	4.2	2.9	5.0	3.2	1.0
3	100°	0	13.50	12.7	–	–	–	–	–	–	–	–
		40	14.45	11.3	0.048	0.040	0.113	0.6	2.2	3.9	5.4	1.2
		80	14.85	10.4	0.078	0.056	0.184	0.5	1.8	3.5	4.9	1.1
							Average	0.6	2.0	3.7	5.2	1.1
4	100°	0	14.60	26.25	–	–	–	–	–	–	–	–
		40	17.00	19.70	0.218	0.098	0.248	2.5	4.8	4.3	6.3	1.3
		80	18.60	18.40	0.262	0.164	0.299	1.5	3.0	2.8	4.2	0.9
							Average	2.0	3.9	3.5	5.2	1.1
5	100°	0	14.35	28.05	–	–	–	–	–	–	–	–
		40	16.05	23.65	0.146	0.070	0.156	1.7	2.9	2.3	3.4	0.7
		80	18.85	17.95	0.336	0.184	0.359	1.9	3.7	3.4	5.1	1.1
							Average	–	3.3	2.9	4.3	0.9
6	120 - 130°	0	14.50	14.05	–	–	–	–	–	–	–	–
		16	17.70	7.70	0.212	0.132	0.453	–	–	50	74	16
7	135°	0	14.50	13.40	–	–	–	–	–	–	–	–
		1.25	15.80	11.40	0.066	0.052	0.148	–	–	140	210	44
		2.25	16.40	10.80	0.086	0.076	0.193	–	–	110	160	35
		3.25	16.70	9.30	0.136	0.088	0.305	–	–	140	210	44
		4.25	17.50	8.50	0.162	0.122	0.363	–	–	135	200	44
							Average	–	–	130	195	42

concentration of the formaldehyde (cf. Tests 1, 2, and 3-5). The bimolecular Equations (10) and (11) yield a satisfactory constancy of the constant (cf. the same tests) for the tests with similar concentration of sulfuric acid. Neither of the foregoing equations is satisfactory for describing the quantitative relationship between the reaction rate and the acid – catalyst concentration. Thus, the value of k_2''' as computed from Equation (10), dealing with a second-power variation with $C_{H_2SO_4}$, falls off with increasing acid concentration, whereas k_2'', computed from Equation (11) for a linear variation with $C_{H_2SO_4}$, rises with increasing acid concentration (compare Tests 1 and 2 with 3-5).

Thus the kinetic order of reaction is fractional, formally speaking, with respect to sulfuric acid.

TABLE 6

Effect of the Concentration of Sulfuric Acid upon the Conversion of Formaldehyde in Aqueous Solution at 148.8°

Expt. No.	Time, hours (τ)	Concentration, wt. %		Formaldehyde consumed, moles/100 g		Converted proportion of $CH_2(OH)_2$, $\underline{y}$	Constants of action		
		Acid, in terms of H_2SO_4	CH_2O	Total $CH_2(OH)_2$	In terms of HCOOH		k_2^{I}, Equation (11)	k_2^{II}, Equation (10)	k_2^{III}, Equation (14)
10	0	3.10	24.80	0	0	0	—	—	—
	9.30	12.50	10.80	0.467	0.384	0.565	5.3	168	21
	15.5	13.70	7.00	0.594	0.434	0.718	6.3	200	25
	21.3	14.65	5.80	0.634	0.472	0.767	6.0	190	24
11	0	6.25	25.00	0	0	0	—	—	—
	1.72	12.70	16.00	0.300	0.264	0.360	6.1	95	19
	3.38	15.20	11.50	0.449	0.366	0.540	6.5	102	20
	6.72	17.55	7.50	0.583	0.462	0.700	6.5	102	20
	9.30	17.85	4.50	0.683	0.476	0.820	8.2	128	25
12	0	12.50	24.50	0	0	0	—	—	—
	0.47	17.45	18.20	0.210	0.202	0.257	7.1	56	17
	0.88	19.95	13.65	0.362	0.304	0.443	8.6	67	20
	1.72	23.35	9.10	0.514	0.440	0.630	9.5	74	22
	2.80	24.30	6.50	0.601	0.482	0.736	9.6	75	22
13	0	20.50	24.50	0	0	0	—	—	—
	0.215	26.15	16.75	0.259	0.230	0.317	11	53	21
	0.385	28.40	13.15	0.379	0.324	0.464	14	67	26
	0.715	31.05	8.05	0.549	0.432	0.673	17	81	31

Special kinetic tests were run in an ultrathermostat to establish this relationship quantitatively, the results being listed in Table 6.

These findings bore out the conclusion set forth above concerning the fractional acid order of reaction, i.e., the kinetic equation ought to look like this:

$$k_2^{III} = \frac{y}{C^{n}_{H_2SO_4}\, a_0 \tau\, (1 - y)}, \qquad (12)$$

where $\underline{n}$ is the exponent of the kinetic order of reaction according to sulfuric acid.

Transforming (12) and taking the logarithm of both sides, we get the expression

$$n \log C_{H_2SO_4} + \log k_2^{III} = \log \frac{y}{a_0 \tau (1 - y)} = \log A. \qquad (12a)$$

Differentiation yields the equation

$$n = \frac{d \log A}{d \log C_{H_2SO_4}}, \qquad (13)$$

where $\underline{n}$ is the slope of a straight line plotted on $\log A - \log C_{H_2SO_4}$ coordinates.

Graphically plotting the experimental data of Table 6 we get $\underline{n} = 1.4$, so that Equation (12) becomes:

$$k_2^{III} = \frac{y}{C^{1.4}_{H_2SO_4}\, a_0 \tau\, (1 - y)}. \qquad (14)$$

We used this last equation to calculate the constants of action in the last column of Table 6.

The values of k_2^{III} thus calculated, as listed in Table 6, are satisfactorily constant for adjacent percentage conversions of formaldehyde throughout a wide range of sulfuric acid concentrations.

From these figures we may conclude that under the experimental conditions employed the process apparently

follows both of the postulated sets of reactions, 40% of the reaction taking place as an interaction between two active coordination compounds.

When we consider the course of the variable k_2'' in each of the experiments, however, we note that it rises regularly as the process continues; this might be due to the error introduced by our using Equation (14) instead of general Equations (5) and (7) for the special case when the equilibrium constant K_C is extremely small.

To test this assumption we ran tests with varying initial concentrations of formaldehyde, the results of which are listed in Table 7.

TABLE 7

Effect of the Initial Concentration of Formaldehyde Upon the Conversion of the Latter in an Aqueous Solution at 148°.

Test No.	Time, hours (τ)	Concentration, wt. %		Formaldehyde consumed, moles/100 g		Converted proportion of $CH_2(OH)_2$, y	Constants of action	
		Acid, in terms of H_2SO_4	CH_2O	Total $CH_2(OH)_2$	In terms of HCOOH		k_1'', Equation (15)	k_2'', Equation (14)
14	0	12.05	10.30	0	0	0	–	–
	0.7	13.60	8.50	0.060	(0.064)	0.175	5.1	17
	1.4	14.65	7.15	0.105	(0.116)	0.306	4.9	17
	2.8	15.80	5.05	0.175	0.152	0.510	4.8	20
	5.6	16.75	3.25	0.235	0.192	0.685	3.9	21
15	0	12.25	13.45	0	0	0	–	–
	0.5	14.30	11.40	0.068	(0.084)	0.152	6.1	15
	1.0	15.55	9.50	0.131	(0.136)	0.292	6.4	17
	2.0	17.05	6.80	0.221	0.196	0.493	6.2	20
	3.8	18.50	4.60	0.295	0.256	0.658	5.1	21
16	0	12.35	27.30	0	0	0	–	–
	0.25	16.10	22.75	0.152	0.152	0.167	13.5	16
	0.5	18.85	18.60	0.290	0.266	0.318	14.0	19
	1.0	21.85	13.70	0.453	0.288	0.498	12.5	20
	2.0	24.35	8.65	0.622	0.490	0.683	10.5	22

TABLE 8

Effect of Temperature upon the Rate of Conversion of Formaldehyde in the Cannizzaro – Tishchenko Reaction in Acid Solutions

Test No.	Temperature	k_2''	Log $k_2'' \cdot 10$		E cal/mole	Temperature coefficient in vicinity of 100°
			Found	Calculated		
1-5	100°	0.1	0.00	0.00	32900	3.3
6	120 - 130	1.6	1.20	1.20 [1]		
7	135	4.2	1.62	1.65		
10-16	148.8	17	2.23	2.23		

The last column in Table 7 gives the constants k_2'', calculated from Equation (14) as before. In the next to the last column we have listed the values of the constant k_1'' as given by the equation

$$k_1'' = \frac{2.3}{\tau C_{H_2SO_4}^{1.4}} \log \frac{1}{(1-y)} \qquad (15)$$

that stems from Equation (7) for $K_C \gg 1$.

As indicated by the results of our preliminary tests, listed in Table 5, however, the monomolecular Equation (15) is refuted by the experimental data, since k_1'' falls proportionally to the decreasing initial concentration of formaldehyde.

The bimolecular constants k_2'', for the same percentage conversions of formaldehyde, remain constant, as in the preceding tests, when the initial formaldehyde concentration is varied from 0.34 to 0.91 mole per 100 grams, i.e., by a factor of 2.7.

Hence, the general Equations (5) and (7) derived theoretically may be replaced by Equation (14) with a high degree of accuracy in the given case, which excludes the likelihood that the assumption made above is correct.

[1] Calculated for the mean temperature of 125°.

Another possible explanation of the rise of k_2''' with increasing percentage conversion of the formaldehyde was the presupposition of autocatalysis, say, as the result of the catalytic influence of the formic acid formed in the reaction, as this acid might also be able to form oxonium compounds with methylene glycol. We know of such compounds of phenol with chloroacetic acid, for example [19].

However, there is no such effect in the present case, apparently. This is borne out by the fact that the rise in the k_2''' constant with percentage conversion is no larger at low concentrations of sulfuric acid than in the tests at high concentrations of sulfuric acid (see Table 6). Hence, a pronounced increase in acidity due to the formic acid produced (by a factor of 4.7 in Test 10) has very little effect upon the overall reaction rate.

Therefore, the most likely reason for the rise in the value of the constant with increasing percentage conversion is the occurrence of secondary conversions of the formaldehyde, the most important being the formation of methylal.

As we have said, this conclusion agrees with the analytical data on the composition of the reaction products in the balance test run at a high percentage of conversion (Table 2).

It follows that the true constants of action are the lower values calculated from Equation (14), corresponding to low percentages of conversion of formaldehyde, when the methanol concentrations are still low and only very little methylal has been formed.

We used Equation (14) to calculate the constants for the experiments described in Table 5; they also remain satisfactorily constant within the limits of accuracy of the preliminary measurements throughout all the tests made at 100°.

This made it possible to use all the tests run in the present research to derive an approximate temperature coefficient of the reaction rate in the given range of experimental conditions.

To do this, we used (of the data in Table 5) the arithmetical means of the experimental values of the constant k_2'', which rose less with time in this case, since most of the tests listed in Table 5 were run at a comparatively low percentage conversion, while for the temperature of 148.8° we took the minimum mean values of k_2''', in accordance with the argumentation set forth above.

These mean values are listed in Table 8, together with the results obtained by working them up.

The values of the velocity constant tabulated in Table 8 lie on a straight line when plotted on $\log k_2''' - \frac{1}{T}$ coordinates (see Figure), so that we get the equation $\log k_2''' = 18.30 - \frac{7200}{T}$, (16)

where T is the absolute temperature.

The high value of the activation energy — 33 kcal/mole — and the correspondingly high temperature coefficient of the reaction rate — 3.3 — indicate the existence of a substantial energy barrier that the reacting molecules have to overcome even when only active coordination compounds interact. Unfortunately, the figures in Table 5 do not enable us to determine the value of n with sufficient accuracy for the order of the reaction in terms of acid at 100°. This makes it impossible as yet to evaluate quantitatively the difference between the activation energy of the reaction of the oxonium coordination compounds with the free methylene glycol molecule and that of the reaction between the oxonium compounds themselves. The satisfactory way in which Tests 1-2 and 3-5 follow Equation (14) indicates, however, that at 100° the value of n_{100} can hardly be much greater than $n_{149} = 1.4$ for 149°. Hence, it is hard to expect any appreciable difference in the values of E for the two reactions.

As for the comparative reaction rates of the active coordination compounds with the methylene glycol in the free and combined state, we can make an approximate calculation therefor.

In view of the proof that we can shift from the general equations (5) and (7) to the bimolecular Equation (14) without introducing any perceptible error, we may conclude that the magnitude of the equilibrium constant of the formation of a coordination compound must be extremely small. Thus, if we use Equation (7), for example, its first term may be ignored only at $K_C < 0.1$ according to the order of experimental error involved.

If we adopt this last value, we get from Equation(1)

$$[CH_2(OH)_2 \cdot H_2SO_4] = 0.1[CH_2(OH)_2][H_2SO_4], \quad (17)$$

whence, substituting the mean values of the concentrations of methylene glycol and sulfuric acid used in the present research (in moles per 100 grams), we get the concentration of the active coordination compound as

$$[CH_2(OH)_2 \cdot H_2SO_4] = 0.1 \cdot 0.5 \cdot 0.15 = 0.0075 \text{ mole/100 grams.}$$

No more than 5% of the total acid or 1.5% of the formaldehyde is combined in the active coordination compound. The latter figure bears out the correctness of the simplification effected above in shifting from Equation (1) to Equation (2). Using these concentrations of the constituents of the reaction mixture, we can make an approximate calculation of the constants: k_1 for the B_1 reaction and k_2 for the B_2 reaction. Inserting the values derived above: $C_{\Sigma} = 0.5$ mole/100 g, $C_{H_2SO_4} = 0.15$ mole/100 g and $C_K = 0.0075$ mole /100 g, in the equation

$$k_2''' \; C_{H_2SO_4}^{1.4} \; C_{\Sigma}^2 = k_1 C_K^2 + k_2 C_K C_{\Sigma}^2 \qquad (18)$$

$$\frac{k_1 C_K^2}{k_2 C_K C_{\Sigma}^2} = \frac{40}{60}, \qquad (19)$$

we get the following values for the constants of action in the respective reactions at 148.8°, corresponding to $k_2''' = 17$:

$$k_1 = 2000, \; k_2 = 50 \text{ and } \frac{k_1}{k_2} = 40.$$

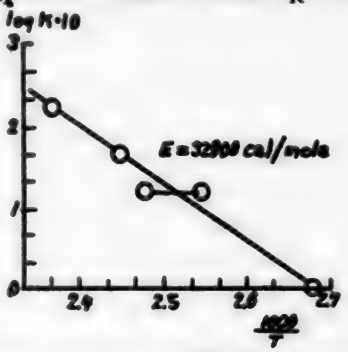

Figure. Variation of k_2''' with temperature.

Thus, as might have been expected, the velocity of interaction between the molecules of the active coordination compound is many times greater than the velocity of the reaction of the coordination compound with the free molecule of methylene glycol.

SUMMARY

1. It has been shown experimentally that the actual concentration of methyl formate in the reaction products substantially exceeds its equilibrium percentage, which confirms V.E.Tishchenko's assumption that the reaction involves the intermediate formation of an ester.

2. A two-stage mechanism is put forward for the Cannizzaro-Tishchenko reaction, the velocity of which is governed by the following parallel reactions:

$$2CH_2(OH)_2 \cdot H_2SO_4 \rightarrow HCOOCH_3 + 2H_2O + 2H_2SO_4;$$

$$CH_2(OH)_2 \cdot H_2SO_4 + CH_2(OH)_2 \rightarrow HCOOCH_3 + 2H_2O + H_2SO_4.$$

3. Kinetic equations are derived to describe the velocity of the principal reaction over a wide range of experimental conditions.

4. The activation energy of the reaction $\underline{E}$ = 32,900 cal/mole, corresponds to a temperature coefficient of the reaction rate of 3.3 in the proximity of 100°.

5. The order of magnitude of the equilibrium constant for the formation of the active coordination compound has been determined to be

$$K_C < 0.1,$$

from which it follows that only little of the acid or the formaldehyde is combined in the coordination compound in the reaction mixture.

6. The approximate ratio of the velocity constant of the interaction between the active coordination compounds themselves (k_1) to that of the coordination compound with a free molecule of methylene glycol has been calculated as (k_2): $k_1/k_2 = 40$.

7. It has been shown that the principal reaction is paralleled by the formation of methylal as a result of the interaction of the formaldehyde with the methanol produced.

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SYNTHESIS OF HYDROCARBONS

XVIII. THE HYDROBROMIDE AND HYDROCHLORIDE OF 2-METHYLPENTADIENE-1,3 AND 4-METHYLPENTADIENE-1,3 IN THE SYNTHESIS OF HYDROCARBONS OF ISOMERIC STRUCTURE

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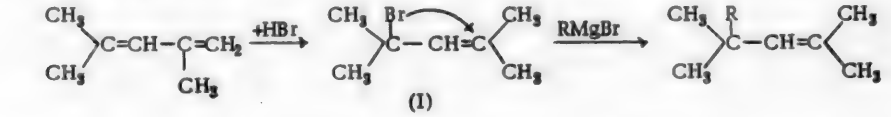
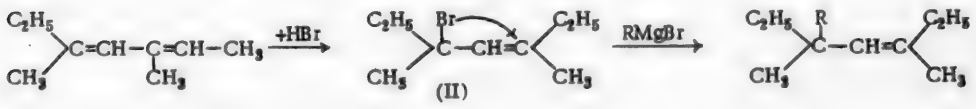
In previous papers one of the present authors has described a method of synthesizing hydrocarbons with a quaternary carbon atom, based upon the reactions of organomagnesium compounds with hydrobromides of diene hydrocarbons — 2,4-dimethylpentadiene-1,3 [1] and 3,5-dimethylpentadiene-2,4 [2]. The hydrobromides of these dienes are alike in these respects: they are unsaturated tertiary bromides (I and II) and homologs of allyl bromide, while their structure renders an allyl rearrangement impossible:

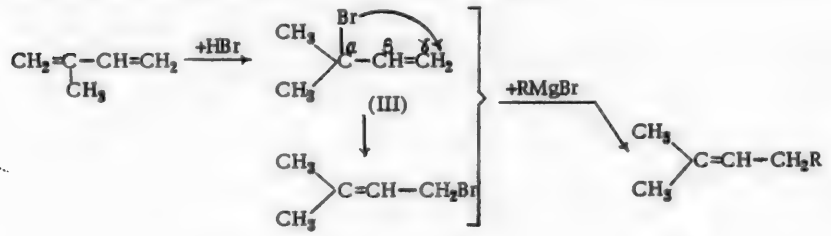


(I)

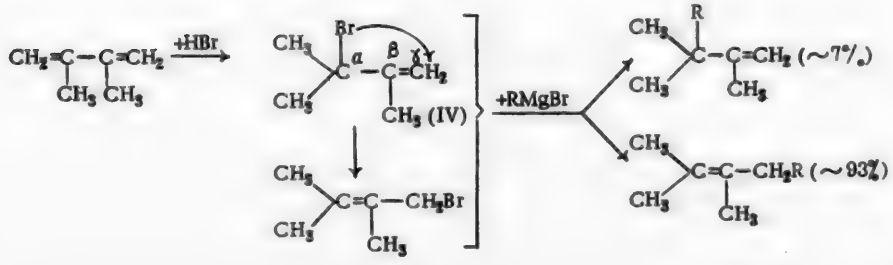


(II)

Tertiary hydrobromides (or hydrochlorides) can also be prepared from other dienes of isomeric structure: isoprene [3-6], 2,3-dimethylbutadiene-1,3 [5-7 and others]. In contrast to the tertiary unsaturated bromides cited above, however, these tertiary unsaturated bromides (III and IV), undergo allyl rearrangement into isomeric primary bromides readily when heated or when subjected to any chemical transformation. Isoprene hydrobromide, for example, reacts with organo-magnesium compounds only in its primary form, and not in its tertiary form [5,8]; 90% of 2,3-dimethylbutadiene-1,3 hydrochloride (or hydrobromide) likewise enters into a reaction of this sort in its primary form [5,9]. Hence, the principal products of these reactions are hydrocarbons that contain no quaternary carbon atom:

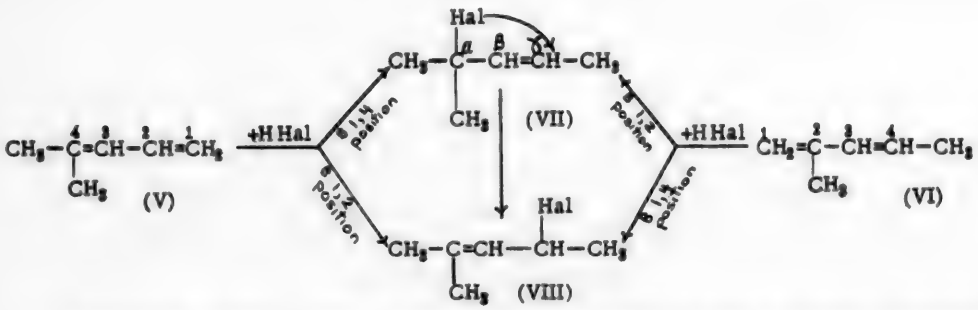


(III)



(IV)

The present paper is a report of an investigation of the reaction of an organo-magnesium compound with the hydrobromide (and the hydrochloride) of 4-methylpentadiene-1,3 and 2-methylpentadiene-1,3. The addition of hydrogen bromide or chloride to these dienes (V and VI) at the 1,2 or 1,4[1] position ought to result in the formation of hydrohalides that can exist, (like the hydrobromides of isoprene and of 2,3-dimethylbutadiene) in two isomeric forms related to an allyl rearrangement: as an unsaturated tertiary halide (VII) and as an isomeric secondary one (VIII):

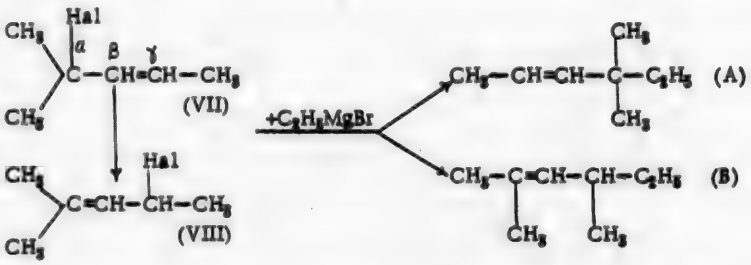


We know that when a hydrogen halide is added to conjugated dienes of isomeric structure (isoprene [3,5,6], 2,3-dimethylbutadiene [6], and the like [10], the initial reaction product is always a tertiary halide, hence, the addition of a hydrogen halide to 2- or 4-methylpentadiene-1,3 also ought to result in the formation of a tertiary hydrohalide (VII) in the initial stage. Yet, though isoprene hydrobromide is distilled through a wide temperature range (twenty degrees) [5,8,11] (since the low-boiling tertiary hydrobromide is readily isomerized during distillation to the high-boiling primary bromide), the hydrobromide of the methylpentadienes secured in the present research distilled within half a degree and evidently was an individual tertiary hydrobromide (VII) unaffected by heating.

Nor was the hydrochloride of the methylpentadienes affected by repeated distillation, or by the action of an excess of hydrogen chloride, i.e., by the conditions in which the tertiary isoprene hydrochloride is rearranged into the isomeric primary compound [3].

The location of the methyl radical at the γ-position to the active halogen atom is a characteristic feature of the structure of the tertiary methylpentadiene hydrobromide and hydrochlorides (VII); this should explain their high stability and reactivity, compared to the tertiary hydrobromides of isoprene and 2,3-dimethylbutadiene (III, IV). We might, therefore, expect the products of the reaction of the hydrohalides of 2- or 4-dimethylpentadiene-1,3 with an organomagnesium compound to contain a high percentage of an alkene with a quaternary carbon atom.

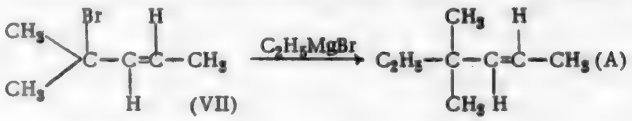
As a matter of fact, a study of this reaction has shown that the hydrochloride and the hydrobromide of the methylpentadienes react vigorously with ethylmagnesium bromide, producing a high yield (50% and 70%, respectively of the theoretical) of a mixture of two isomeric alkenes—4,4-dimethylhexene-2 (A) and 2,4-dimethylhexene-2 (B):



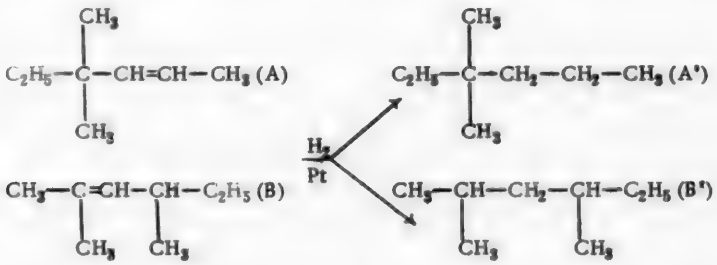
The presence of 4,4-dimethylhexene-2 (A) was proved by the fact that oxidizing the resultant alkene mixture with potassium permanganate yielded acetic and dimethylethylacetic acids. Bromination of the

[1] If the hydrogen halide were added to both of the dienes at the 3,4 position, we would get hydrohalides that did not belong to the allyl halide series and would not react with organomagnesium compounds under ordinary conditions.

mixture gave us a 50% yield of a stable dibromide, as is typical for a symmetrical disubstituted homolog of ethylene, which is what 4,4-dimethylhexene-2 (A) is; this was further confirmation of its presence in the alkene mixture we had produced. The presence of 2,4-dimethylhexene-2 (B) in this mixture was proved by our securing acetone peroxide—the most characteristic product of the ozonidation of 2,4-dimethylhexene-2—when we ozonized the mixture. Investigation of the Raman spectrum of the alkene mixture yielded an interesting conclusion regarding the geometrical configuration of 4,4-dimethylhexene-2 (A), namely: this hydrocarbon had a trans configuration, so that the initial tertiary hydrohalide (VII) was a pure trans form:



The quantitative composition of the alkene mixture we were investigating was established by hydrogenating them and comparing the Raman spectrum of the resultant mixture of alkanes with the spectra of the two components of that mixture: 3,3-dimethylhexane (A') and 2,4-dimethylhexane (B'):



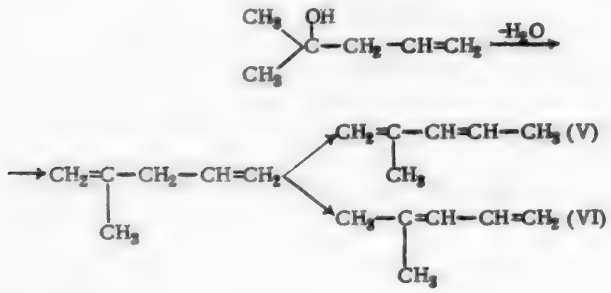
This spectroscopic examination indicated that the resultant alkane mixture contained some 40% of 3,3-dimethylhexane (A') and some 60% of 2,4-dimethylhexane (B'); hence, the original mixture of alkenes contained the same proportion of the respective alkenes, namely: some 40% of 4,4-dimethylhexene-2 (A) and some 60% of 2,4-dimethylhexene-2 (B).

Therefore, the tertiary allyl halides (the hydrobromide and the hydrochloride of 2- or 4-methylpentadiene-1,3), which possess a methyl group in the γ-position to the active halogen atom (VII), are much more stable than other tertiary allyl halides (the hydrobromides or hydrochlorides of isoprene and of 2,3-dimethylbutadiene), which do not possess this sort of structure (III and IV).

The stability of the tertiary hydrohalides (VII) of 2- or 4-methylpentadiene-1,3 in reactions with organomagnesium compounds makes it possible to use these halides for synthesizing hydrocarbons containing a quaternary carbon atom, irrespective of the allyl rearrangement they frequently experience in the course of the reaction.

EXPERIMENTAL

The initial dienes—2-methylpentadiene-1,3 (V) and 4-methylpentadiene-1,3 (VI)—were prepared as a mixture (59% yield); b.p. 72.5-75.5° at 761 mm, n_D^{20} 1.4474 and d_4^{20} 0.7147; containing 30-35% of V and 65-70% of VI) by dehydrating dimethylallylcarbinol with chromic oxide on alumina (the preparation of these dienes has been described in our preceding paper [12].



Addition of hydrogen chloride to the mixture of methylpentadienes. This reaction was carried out under conditions that excluded the possibility of an allyl rearrangement of the resultant tertiary allylic chloride (VII) (4-chloro-4-methylpentene-2), i.e., with deep chilling and the introduction of less hydrogen chloride than called for by the equation [3]. The reaction vessel was chilled to −20--25°, and 17 g (about 0.2 mole) of the methylpentadiene mixture was placed in it together with 2-3 g of absolute ether (to insure better dissolution of the hydrogen chloride); hydrogen chloride was added until the gain in weight totaled 5 g (0.14 mole). Then a current of anhydrous nitrogen was passed through the reaction mixture, deeply chilled (to −70 or −80°), to remove all traces of any unreacted hydrogen chloride.

The synthesized hydrochloride (which is not described in the literature) proved to be entirely stable—it distilled within half a degree and possessed the following constants:

B.p.46.5-47° (83 mm); n_D^{20} 1.4438; d_4^{20} 0.8969 MR_D 35.12; calculated 34.31; EM_D 0.81 (the presence of exaltation of the molecular refraction is a characteristic of allylic halides). The percentage of chlorine in the hydrochloride was determined by the M.O.Korshun and M.N.Chumchenko method [13]: 2.5600 mg substance: 1.077 ml 0.02 N $AgNO_3$; 1.4589 mg substance: 0.6106 ml 0.02 N $AgNO_3$. Found %: Cl 29.82, 29.66. $C_5H_{11}Cl$: Calculated %: Cl 29.90.

A hydrochloride with the same constants was secured when we prepared the methyl-pentadiene hydrochloride with an excess of hydrogen chloride (a 10 g gain in weight per 17 g of the diene mixture); i.e., under conditions that promote an allyl rearrangement.

In later tests the hydrochloride of the 2- and 4-methylpentadiene-1,3 was prepared (with a yield of 81% of the theoretical) by adding a stoichiometric quantity of hydrogen chloride to the dienes.

Adding hydrogen bromide to the methylpentadiene mixture. The hydrogen bromide was first freed of any bromine and dried by passing it through a system of tubes containing red phosphorus on glass beads and calcined calcium chloride. Chilling with snow and salt was used for the reaction; the addition of the stoichiometric quantity of hydrogen bromide (15 g of hydrogen bromide to 15 g of the methylpentadiene mixture) was complete within 20-30 minutes, the reaction being slow at the start and proceeding at high velocity only after some time had elapsed. After the unreacted hydrogen bromide had been removed from the synthesized hydrobromide (85% of the theoretical yield) by passing anhydrous nitrogen through it at −70° and vacuum distillation, it possessed the following constants (this compound is not described in the literature):

B.p. 49.5-49.7° (30 mm); 26° (7 mm); n_D^{20} 1.4787; d_4^{20} 1.2077; MR_D 38.50; calculated 37.21, EM_D 1.29.

4.480 mg substance: 7.260 mg CO_2; 2.785 mg H_2O. 4.495 mg substance: 7.302 mg CO_2; 2.760 mg H_2O. 1.5972 mg substance: 0.6153 ml 0.02 N $AgNO_3$. 2.1860 mg substance: 0.6702 ml 0.02 N $AgNO_3$. Found %: C 44.22, 44.33; H 6.95, 6.87; Br 48.85; 49.00. $C_5H_{11}Br$: Calculated %: C 44.19; H 6.80, Br 49.00.

The hydrobromide proved to be wholly stable, its constant undergoing no change after repeated distillation or after standing for several days (at 4 or 5°).

Adding hydrogen bromide to individual 4-methylpentadiene-1,3 (VI) with a b.p. of 76.3° at 762 mm; n_D^{20} 1.4520 and d_4^{20} 0.7200, separated from the methylpentadiene mixture by treating the latter with maleic anhydride [14], yielded a hydrobromide with the same constants as those specified above:

B.p.53.5° (35 mm); 49.5° (30 mm); n_D^{20} 1.4795; d_4^{20} 1.2062.

Thus, 4-methylpentadiene-1,3 (VI) and a mixture of that hydrocarbon with the isomeric 2-methylpantadiene-1,3 (V) yield the same hydrobromide.

Reaction of ethylmagnesium bromide with the hydrochloride and hydrobromide of 2- and 4-methylpentadiene-1,3. A 1:1 ether solution of the hydrochloride (the hydrochloride was not distilled, but was placed in reaction immediately after its recovery from 20.5 g of the diene mixture) was chilled with dry ice and alcohol and then reacted with ethylmagnesium bromide (43.5 g of ethyl bromide and 9.8 g of magnesium), with constant stirring of the reaction mixture chilled to −20—60° (the molar proportions of the ethyl bromide, magnesium, and the hydrochloride being 1.5:1.6:1). After all the hydrochloride had been added (during the course of one hour), the reaction mass was stirred for another 2.5 hours at −20--30° and then stirred 4-5 hours while being heated the next day. It was decomposed by pouring the reaction mixture over ice and adding acetic acid (15%).

After the customary treatment of the ether extract and the driving off of the ether, the reaction product was distilled with sodium into a column with an efficiency of 40 theoretical trays. All of it distilled within a narrow temperature range, its constants being as follows (the yield was 55% of the theoretical):

B.p. 107-107.3° (761 mm); n_D^{20} 1.4142; d_4^{20} 0.7210; MR_D 38.91; calculated 38.68.

The ethylmagnesium bromide was reacted with the hydrobromide secured from the 20.5 g of the methylpentadiene mixture in the same manner and using the same proportions as employed for the reaction of ethylmagnesium bromide with the hydrochloride, the only difference being that the hydrobromide was placed in the reaction with the reaction mixture chilled to a still lower temperature: down to —40--50°.

The product of this reaction possessed exactly the same constants as those cited above, though its yield was higher—70% of the theoretical, based on the initial methylpentadiene mixture:

B.p. 107.2-107.4° at 756 mm; n_D^{20} 1.4146; d_4^{20} 0.7213.

3.800 mg substance: 11.925 mg CO_2; 4.888 mg H_2O. 3.785 mg substance: 11.899 mg CO_2; 4.830 mg H_2O. Found %: C 85.62, 85.74; H 14.39; 14.28: C_8H_{16}. Calculated %: C 85.62; H 14.38.

It should be noted that exactly the same results were obtained whether the hydrobromide was vacuum-distilled before the reaction or reacted directly after it had been prepared from the methylpentadiene mixture.

The constants of the collected hydrocarbon fraction were quite close to those of two possible reaction products: 4,4-dimethylhexene-2 (A) and 2,4-dimethylhexene-2 (B) (see Table).

		B.p.	n_D^{20}	d_4^{20}
Hydrocarbon fraction collected . . .		107.2-107.4° (756 mm)	1.4146	0.7213
4,4-Dimethylhexene-2 (A). .	[15] . .	105.4-106 (760 mm)	1.4120	0.7202
	[16] . .	106.3-106.7 (749 mm)	1.4155	0.7223
2,4-Dimethylhexene-2 (B). .	[17] . . .	108.9-109 (760 mm)	1.4144	0.7223

The Raman spectrum of the fraction with a b.p. of 107.2-107.4° contained only one frequency in the double-bond region: 1674 cm^{-1}. This frequency is typical of trisubstituted homologs of ethylene, such as 2,4-dimethylhexene-2 (B), as well as of the trans form of disubstituted ethylene homologs, such as 4,4-dimethylhexene-2 (A). Thus, 4,4-dimethylhexene-2 had a trans configuration; hence, we have to assign the same configuration to the tertiary hydrohalide (VII) of 4- and 2-methylpentadiene-1,3.

Bromination of the collected hydrocarbon fraction (6 g) was effected in a chilled chloroform solution. The reaction mixture was processed in the usual manner, the chloroform being driven off (at reduced pressure), and the bromination product fractionated in vacuum, yielding a dibromide (50% of the theoretical yield) that possessed the following constants:

B.p. 101-103° (10 mm), n_D^{20} 1.5113; d_4^{20} 1.4943; MR_D 54.56; calculated 54.67.

Figures in the literature for 4,4-dimethylhexene-2 dibromide (4,5-dibromo-3,3-dimethylhexane) [15]: b.p. 92-93° (4 mm); n_D^{20} 1.5113; d_4^{20} 1.5148; MR_D 54.21.

Hence, bromination yielded a stable dibromide as is typical of a symmetrical disubstituted homolog of ethylene, such as 4,4-dimethylhexene-2 (A) is. 2,4-Dimethylhexene-2 (B), a trisubstituted homolog of ethylene, ought to be converted by bromine into an unstable dibromide that evolves hydrogen bromide readily, giving rise to an unsaturated monobromide (as a matter of fact, a low-boiling fraction that darkened upon standing was driven off during the distillation of the bromination product).

To judge by the yield of the stable dibromide, the percentage of 4,4-dimethylhexene-2 (A) in the analyzed hydrocarbon fraction was at least 50%.

Oxidation of the hydrocarbon fraction (8 g) was effected with a 4% water—acetone (20% acetone) solution of permanganate in the cold, with vigorous stirring. The customary processing of the reaction mixture yielded 1.2 g of acetic acid with a b.p. of 117-120°, and dimethylacetic acid with a b.p. of 187-190° at 760 mm (no intermediate fraction was found).

According to A.E.Favorsky [18] dimethylethylacetic acid has a b.p. of 186-187.5° (755 mm). Analysis of the acid with a b.p. of 187-190° and of its silver salt indicated a composition that was that of dimethylethylacetic acid:

3.550 mg substance, 8.057 mg CO_2; 3.290 mg H_2O. 3.233 mg substance: 7.341 mg CO_2; 3.011 mg H_2O. Found %: C 61.90; 61.93; H 10.30, 10.35. $C_6H_{12}O_2$. Calculated %: C 62.07; H 10.35. 0.1000 g substance: 0.0481 g Ag. Found %: Ag 48.10. $C_6H_{11}O_2Ag$. Calculated %: Ag 48.37.

The acetic acid (the fraction with a b.p. of 117-120°) was identified by preparing acetanilide with a m.p. of 115° (after recrystallization); the mixed melting point exhibited no depression.

The production of acetic and dimethylethylacetic acids confirmed the presence of the 4,4-dimethylhexene-2, a hydrocarbon with a quaternary carbon atom (A), in the 107.2-107.4° hydrocarbon fraction.

The other possible constitutent of this fraction — 2,4-dimethylhexene-2, a trisubstituted homolog of ethylene (B), is apparently oxidized by potassium permanganate more slowly than is 4,4-dimethylhexene-2, a disubstituted homolog of ethylene; therefore the absence in the oxidation products of methylethylacetic acid, which ought to appear as a result of oxidation of 2,4-dimethylhexene-2, cannot be regarded as evidence that this hydrocarbon is not present in the analyzed fraction. The presence of 2,4-dimethylhexene-2 in the fraction was proved by means of ozonidation.

Ozonidation of the hydrocarbon fraction (3 g) was effected in a chloroform solution. After the solvent had been driven off in vacuo, the ozonides were decomposed by prolonged heating with water; then the reaction mixture was heated with 2 ml of hydrogen peroxide, neutralized with soda, and distilled with steam. The distillate contained white crystals, consisting of acetone peroxide, with a m.p.of 131.5-132.5° (the literature [19] gives the m.p. as 132-133°). The production of acetone peroxide, the most typical product of the ozonidation of 2,4-dimethylhexene-2 (B), proved that the latter was present in the tested hydrocarbon fraction (the acids—acetic, methylethylacetic and dimethylethylacetic—were not isolated from the ozonidation products).

Thus, bromination, oxidation, and ozonidation combined to show that the product of the reaction of 4-methylpentadiene-1,3 (or 2-methylpentadiene-1,3) hydrobromide with ethylmagnesium bromide is a mixture of 4,4-dimethylhexene-2 (A) and 2,4-dimethylhexene-2 (B). The qualitative and quantitative composition of this mixture was finally established by hydrogenating it to a corresponding alkane mixture and then analyzing the latter optically.

Hydrogenation of the mixture of alkenes (50 g) was performed at 160-165° over platinized charcoal (15% (15% Pt).

Part of the catalysis product was distilled into a small dephlegmator for analysis of its Raman spectrum.[1] In this analysis, chloroform was used as an internal standard.

Several Raman spectra of the test alkane mixture and of 2,4-dimethylhexane, to which a certain amount of chloroform was added, were photographed on the same plate. Blackening marks were placed on the plate, a photometric procedure [20] being employed to determine the ratio of the intensity of the line of the 2,4-dimethylhexane (B') selected for analysis to that of the 669 cm^{-1} line of chloroform in the spectra of the individual hydrocarbon and of the tested mixture of alkanes. (The 669 cm^{-1} chloroform line did not coincide with any other lines in the spectra, as had been determined by preliminary photographs.) The percentage of 2,4-dimethylhexane (B') was determined from its most intense line (827 cm^{-1}). Two independent, parallel determinations were made for other, less intense lines of this paraffin hydrocarbon, all these determinations yielding results that were close together. The Raman spectrum of the alkane mixture is given below:[2]

270(0); 318(3;b); 339(0.5); 358(0.8); 416(1.5;b); 441(1.8); 467(1); 500(0.6); 715-735(3;b); 767(1.5); 794(0.5); 815(1.2) 827(5); 857(1.2); 875(2); 907(3.5;b); 930(1); 956(4); 996(1.8); 1040-1050(2.5;b); 1085(1); 1100-1107(3;b); 1148(2); 1170(4); 1193(3); 1241(1.2); 1267 (1); 1309(1.8;b); 1344(1); 1382(1); 1443(10); 1463(9).

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[1] We wish to express our gratitude to V.M.Tatevsky for his counsel concerning the optical analysis.

[2] The intensities of the analytical lines, 827 cm^{-1} (for 2,4-dimethylhexane [21]) and 715-735 cm^{-1} (for 3,3-dimethylhexane [22]) in the spectrum of the tested mixture were determined photometrically; the intensities of the other lines were estimated visually; b denotes a wide band.

The concentration of 2,4-dimethylhexane by weight in the tested alkane mixture, N_2, was determined from the formula:

$$N_2 = \frac{N_1 C_2}{C_1} \cdot \frac{I_2}{I_2'} \cdot \frac{I_1'}{I_1} \cdot \frac{1}{100 - C_2},$$

Where N_1 is the concentration of this hydrocarbon by weight in its mixture with chloroform; C_1 is the concentration of chloroform by weight in the same mixture; C_2 is the concentration of chloroform by weight in the chloroform solution of the alkane mixture, and I_1'/I_1 and I_2/I_2', respectively, are the ratio of the intensity of analytical line 827 cm^{-1} for 2,4-dimethylhexane in its mixture with chloroform to that of the 669 cm^{-1} chloroform line, measured in the spectrum of the chloroform solution of 2,4-dimethylhexane, and in the spectrum of the chloroform solution of the test alkane mixture.

The optical analysis indicated that the alkane mixtures produced by hydrogenating the products of the reaction of ethylmagnesium bromide with the hydrobromide and the hydrochloride of the methylpentadienes have compositions that are very much alike; in the former case, the percentages of 2,4-dimethylhexane and 3,3-dimethylhexane were some 61 ±5% and some 39 ± 5% respectively, the corresponding figures for the latter case being 58 ± 5% and 42 ±5%.

Part of the resultant alkane mixture (32 g) was distilled with sodium into a column with an efficiency of 40 theoretical trays. The alkane mixture distilled throughout a wide temperature range (107-111°), in sharp contrast to the original mixture of alkenes, which distilled into the same column in a narrow range (107.2-107.4°). Refractionation (into a column with 60 theoretical trays) enabled us to separate the two components – 2,4-dimethylhexane (5 g) and 3,3-dimethylhexane (6 g), with an intermediate fraction totalling 17 g – in this alkane mixture (with a b.p. of 107-111°).

2,4-Dimethylhexane: b.p. 109° (768 mm); n_D^{20} 1.3960; d_4^{20} 0.7018; MR_D 39.11; calculated 39.14.
Literature data: b.p. 108.5-109° (740 mm); n_D^{20} 1.3967; d_4^{20} 0.7032 [23].

3,3-Dimethylhexane: b.p. 111-111.1° (768 mm); n_D^{20} 1.4005; d_4^{20} 0.7085; MR_D 39.13; calculated 39.14.
5.238 mg substance: 16.143 mg CO_2; 7.365 mg H_2O. 4.320 mg substance: 13.330 mg CO_2; 6.080 mg H_2O.
Found %. C 84.10, 84.21; H 15.73, 15.75. C_8H_{18}. Calculated %. C 84.12; H 15.88.
Literature data: b.p. 110.9° (754 mm); n_D^{20} 1.4014; d_4^{20} 0.7094 [24]; b.p. 110.7-111.2° (760 mm); n_D^{20} 1.3992; d_4^{20} 0.7078 [15].

Investigation of the Raman spectrum of the 3,3-dimethylhexane indicated that it contained no trace of 2,4-dimethylhexane.

Thus, about 40% of the hydrochloride and the hydrobromide of 2- or 4-methylpentadiene-1,3 react with ethylmagnesium bromide in their tertiary form, yielding an alkene with a quaternary carbon atom – trans-4,4-dimethylhexene-2, hydrogenation of which yields 3,3-dimethylhexane.

SUMMARY

1. Adding hydrogen chloride and bromide to 2- and 4-methylpentadiene-1,3 results in the formation of unsaturated tertiary halides of the allyl type that are unaffected by heating or distillation.

2. The hydrochloride and the hydrobromide of 2- and 4-methylpentadiene-1,3 (not described in the literature) react vigorously with ethylmagnesium bromide, yielding a mixture of two isomeric alkenes with adjacent boiling points: 4,4-dimethylhexene-2 and 2,4-dimethylhexene-2 (the yields being 55% and 70% of the theoretical, respectively). The formation of these two hydrocarbons is due to the fact that a tertiary hydrogen halide and an isomeric secondary hydrogen halide, related via an allyl rearrangement, take part in the reaction with the ethylmagnesium bromide.

3. The qualitative composition of the resultant alkene mixture was corroborated by the results of bromination, oxidation, ozonidation, and optical analysis. The quantitative composition of this mixture (some 40% of the hydrocarbon with a quaternary carbon atom – 4,4-dimethylhexene-2, and some 60% of the 2,4-dimethylhexene-2) was established by hydrogenating the mixture and analyzing the composition of the resulting alkane mixture by the Raman spectrum method.

4. It has thus been found that about 40% of the hydrochloride and the hydrobromide of 2- and 4-methylpentadiene-1,3 react with an organomagnesium bromide as tertiary allylic halides, which are characterized by having a methyl radical at the δ-position to the active halogen atom. In this respect the hydrohalides of 2- and 4-methylpentadiene-1,3 differ from the hydrohalides of isoprene and of 2,3-dimethylbutadiene-1,3, which react with organomagnesium compounds almost exclusively as primary allylic halides (only very slightly as tertiary halides).

5. It has been found (by the Raman spectrum method) that the 4,4-dimethylhexene-2 formed from the tertiary hydrohalide of 2- and 4-methylpentadiene-1,3 has a trans configuration, so that the initial unsaturated tertiary halide must possess the same configuration.

6. The high yield (70% of the theoretical) of the mixture of alkenes produced by reacting ethylmagnesium bromide with the hydrobromide of 2- and 4-methylpentadiene-1,3 and the substantial percentage of 4,4-dimethylhexene-2 (some 40%) in this mixture and of 3,3-dimethylhexane in the corresponding mixture of alkanes makes it possible to utilize the reaction studied in this paper for synthesizing alkanes with quaternary carbon atoms.

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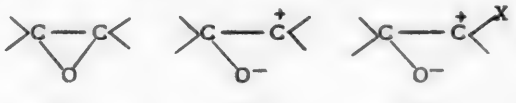
OXIDATIVE AND OXIDATIVE-HYDROLYTIC TRANSFORMATIONS OF ORGANIC MOLECULES

XX. THE STRUCTURE OF OXIDES OF UNSATURATED COMPOUNDS

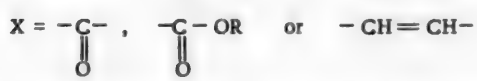
M. M. Shemyakin, D. A. Bochvar, and L. A. Shchukina

As we have stated more than once [1-11], the oxides of various types of unsaturated compounds are substances that are frequently the end products in purely oxidative transformations of organic molecules, whereas these oxides occur as intermediate products in oxidative-hydrolytic reactions, which then undergo a series of subsequent changes.

It is natural that the structure and properties of oxides of unsaturated compounds are essential factors in a correct understanding of oxidative-hydrolytic transformations. Up to very recently the structure of compounds of this type has been represented by formulas of Type (I), which have been generally adopted. Some years ago, however, P. Karrer [12] asserted that the oxides of unsaturated compounds ought to be subdivided into two kinds: the first, not possessing an oxidizing ability and possessing a Type (I) structure, and the second, possessing oxidizing ability and a structure that was expressed by formulas of Type (II).



(I) (II) (III)



P. Karrer emphasized that oxides of the first kind are characterized by an absence of substituents in their molecules that could polarize the C — O bond of the oxide group, while oxides of the second kind had such substituents. We know, as a matter of fact, that ethylene oxide, as well as its homologs and derivatives, which do not have strongly polarizing substituents immediately adjacent to the oxide group, have no oxidizing ability, whereas the oxides of α, β-unsaturated ketones and of some esters of α,β-unsaturated acids, as well as oxides of the carotenoids are oxidants [13].[1)] It is these comparisons that lead P. Karrer to the following conclusions:

1) When the oxide molecules have no polarizing substituents, their structure is expressed by Type (I) formulas, and their oxidic oxygen, connected by two covalent bonds to the carbon atoms, cannot possess oxidative ability.

2) When the oxide molecules contain substituents that can polarize the C — O bond of the oxide group, the structure of the oxides is represented by Type (II) formulas, or more accurately Type (III), so that they exhibit the properties of oxidants.

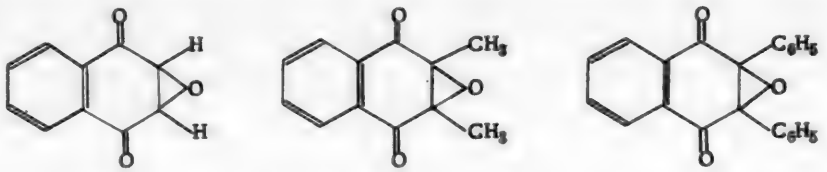
In our opinion P. Karrer's views are wrong, for the following reasons.

First, they are contradicted by certain arguments of a general nature. For, if we extend Karrer's standpoint consistently, the oxidative ability of oxides must be characterized quantitatively, say, by the values of the oxidative potentials determined under certain standard conditions. But then we will undoubtedly find a gradual transition from oxides with low oxidative ability to oxides with high oxidative ability, thus making any division of oxides into two kinds according to their oxidizing ability completely arbitrary.

Second, in expounding his views, P. Karrer ignores modern concepts of the nature of the polarizing action of the substituents he considers. In fact, he assigns Type (III) formulas to the oxides of α,β-unsaturated ketones and of esters of α,β-unsaturated acids, in these formulas the C — O bond of the oxide group being polarized in such a way as to produce a positive charge on the carbon atom linked to the carbonyl or carbalkoxy group. It is a matter of common knowledge, however, that a group of this sort can exert a polarizing effect, due to the shift of electrons only toward these groups. Hence, since P. Karrer ascribes a polarizing action to the carbonyl and carbalkoxy groups that is contrary to what is actually so, the Type (III) formulas proposed by him for these oxides are incorrect.

[1)] Oxides of α,β-unsaturated ketones and of esters of α,β-unsaturated acids, like the oxides of tertiary amines and iodooso compounds, oxidize monovalent negative iodine to free iodine.

Third, P. Karrer's views are contradicted by our experimental data on the oxidative ability of quinone oxides. On the basis of the concepts put forward by P. Karrer it should have been expected that such oxides as 1,4-naphthoquinone oxide, 2,3-dimethyl-1,4-naphthoquinone oxide, and 2,3-diphenyl-1,4-naphthoquinone oxide must not possess oxidative ability.



As a matter of fact, however, though the molecules of these oxides do possess carbonyl groups, the symmetrical structure of the molecules prevents these groups from affecting the degree of polarization of the C — O bonds of the oxide groups. Therefore, on the basis of P. Karrer's views, we should presuppose that all three of these oxides, which do not have structures represented by Type (II) formulas, will not exhibit any oxidative action. But 1,4-naphthoquinone oxide [10], 2,3-dimethyl-1,4-naphthoquinone oxide, and 2,3-diphenyl-1,4-naphthoquinone oxide (cf the experimental section below), as well as several other oxides of substituted p- benzo and p-naphthoquinones that we have investigated [3,10], do exhibit fairly well pronounced oxidative ability, readily oxidizing monovalent negative iodine to free iodine, for example, the oxides themselves being reduced to the respective quinones.

The foregoing compels us to conclude that P. Karrer's notions concerning the structure of oxides of unsaturated compounds are wrong.

EXPERIMENTAL

We have described the oxidative ability of the 2,3- oxides of 1,4-naphthoquinone, 2-methyl-1,4-naphthoquinone, 3-phenyl-1,4-naphthoquinone, potassium 2-methyl-1,4-naphthoquinone-3-sulfonate, and of 6-phenyl-1,4-benzoquinone in previous reports [3,10]. The results of our investigation of the oxidative ability of the 2,3- oxides of 2,3-dimethyl-1,4-naphthoquinone and of 2,3-diphenyl-1,4-naphthoquinone are set forth below.

1. Properties of 2,3-dimethyl-1,4-naphthoquinone oxide. 0.2284 g of 2,3-dimethyl-1,4-naphthoquinone oxide (m.p. 103-104° [14]) were dissolved in 45 ml of glacial acetic acid, and 5.0 g of potassium iodide was added to the solution. The solution (which was colored a light-brown even at room temperature by the iodine liberated) was boiled for 45 minutes, then cooled and diluted with 150 ml of water. The iodine liberated was back-titrated with a 0.1 N solution of hyposulfite, the amount of iodine being found to be 0.2774 g (96.6%, based on the initial oxide). After titration, the solution was extracted several times with ether, the ether solution being washed three times with a 10% aqueous solution of soda and then several times with water. The neutral ether solution was boiled with activated charcoal and dried with sodium sulfate. After the ether had been driven off, the yellow crystalline residue was dried to constant weight in vacuo at 80° and 5 mm. The melting point of the substance produced was 126°. A sample mixed with 2,3-dimethyl-1,4-naphthoquinone melted at the same temperature. The resultant quinone weighed 0.2056 g, this yield being 97.8%, based on the initial oxide.

2. Synthesis and properties of 2,3-diphenyl-1,4-naphthoquinone oxide. a) Synthesis of 2,3-diphenyl-1,4-naphthoquinone. 7 g of 2-phenyl-1,4-naphthoquinone, 105 ml of glacial acetic acid, and 8 g of benzoyl peroxide were heated to 115° for 2 hours 30 minutes. When the reaction was over, the solution was cooled and then poured into 300 ml of a saturated aqueous solution of sodium chloride. The yellow precipitate was filtered out, washed with water, and recrystallized from alcohol at first and then from glacial acetic acid. M.p. 139-140° [15]. Weight 2.3 g (25% yield).

b) Synthesis of 2,3-diphenyl-1,4-naphthoquinone oxide. 4.6 ml of 27% hydrogen peroxide was added to a hot solution of 2.1 g of 2,3-diphenyl-1,4-naphthoquinone in 50 ml of alcohol, followed by 11 ml of a 10% aqueous solution of soda. The solution was heated to a boil and then boiled for 7-8 minutes, after which it was cooled and poured into 200 ml of water. The precipitate was filtered out, washed with water, and recrystallized from alcohol containing activated charcoal. M.p. 155-156°. Weight 1.15 g; 52% yield.

Found %: C 80.81; H 4.36. $C_{22}H_{14}O_3$. Calculated %: C 80.98; H 4.29.

c) Properties of 2,3-diphenyl-1,4-naphthoquinone oxide. The oxidative properties of 2,3-diphenyl-1,4-naphthoquinone oxide were determined under the same conditions as those described above for 2,3-dimethyl-1,4-naphthoquinone oxide. The oxide sample weighed 0.2416 g; the iodine was found to total 0.1862 g (98.9%, based on the initial oxide). The ether solution yielded 0.2300 g of 2,3-diphenyl-1,4-naphthoquinone (m.p. 139-140°), or 100.1%, based on the initial oxide.

SUMMARY

It has been shown that the concepts put forward by P. Karrer concerning the structure of oxides of unsaturated compounds are wrong.

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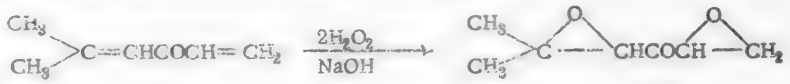
DERIVATIVES OF ACETYLENE 132. α-KETONIC ETHERS AND THEIR TRANSFORMATIONS

III. THE MONOETHER OF β,β-DIMETHYL DIVINYL KETONE. OXIDATION OF VINYL ISOBUTYL KETONE AND ETHYL ISOBUTENYL KETONE WITH ALKALINE HYDROGEN PEROXIDE

I. N. Nazarov and A. A. Akhrem

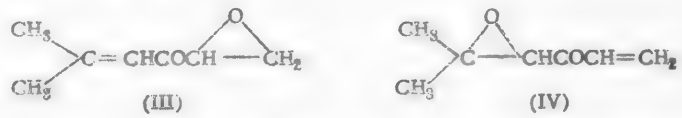
In our previous report we showed [1] that when β,β-dimethyl divinyl ketone (I) is oxidized with two moles of alkaline hydrogen peroxide a 60% yield of the corresponding ketonic diether (II) is obtained:



(I) (II)

We were interested in making a study of the behavior toward alkaline hydrogen peroxide of the double bonds of β,β-dimethyl divinyl ketone (I), which possess differing degrees of substitution.

When β,β-dimethyl divinyl ketone (I) is oxidized with one molecule of alkaline hydrogen peroxide, it is principally the unsubstituted vinyl group that enters into reaction, giving rise to a 40% yield of the unsaturated monoether (III):

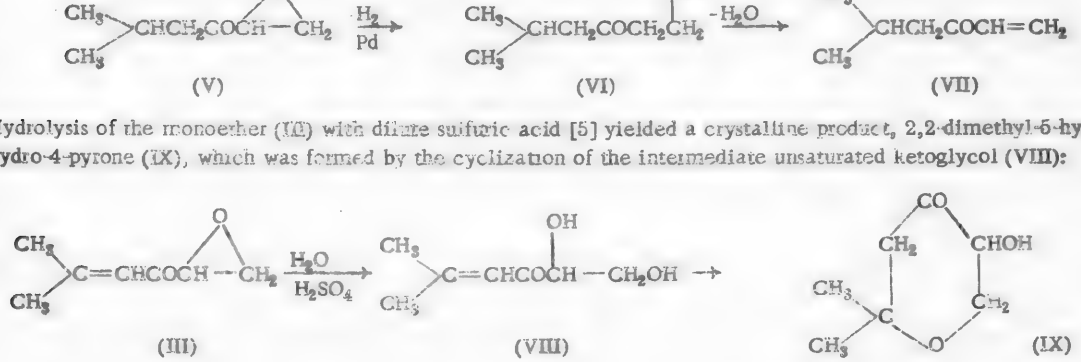


(III) (IV)

Alongside the monoether (III), this reaction also yields the diether (II) and a small quantity of the isomeric monoether (IV), so that this reaction, in contrast to other addition reactions [2], is not rigidly selective. In contrast to the divinyl ketones, oxygen is added principally at the substituted double bond when ethylenic hydrocarbons are oxidized by acid hydroperoxides [3]. When the monoether (III) is partially hydrogenated (1 mole of H_2) in the presence of a palladium catalyst, it is chiefly the double bond that is hydrogenated, yielding the ketonic ether of vinyl isobutyl ketone (V). Exhaustive hydrogenation of the monoether (III) with a palladium catalyst results in rupture of the oxide ring, yielding the β-ketol (VI), which yields the previously described [4] vinyl isobutyl ketone (VII) when dehydrated with p-toluenesulfonic acid:

(V) (VI) (VII)

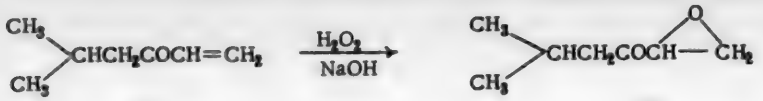
Hydrolysis of the monoether (III) with dilute sulfuric acid [5] yielded a crystalline product, 2,2-dimethyl-6-hydroxytetrahydro-4-pyrone (IX), which was formed by the cyclization of the intermediate unsaturated ketoglycol (VIII):



(III) (VIII) (IX)

The conversion of the unsaturated ketonic ether (III) into the hydroxypyrone (IX) by the action of dilute sulfuric acid is not a smooth reaction. In addition to the crystalline hydroxypyrone (IX), we get the ketoglycol (VIII) and an isomeric low-boiling product of unknown composition. Hydrolyzing the monoether (III) with water yielded the unsaturated ketoglycol (VIII).

We also synthesized the saturated ketonic ether (V) by oxidizing vinyl isobutyl ketone (X) with alkaline hydrogen peroxide, the yield being 60%:

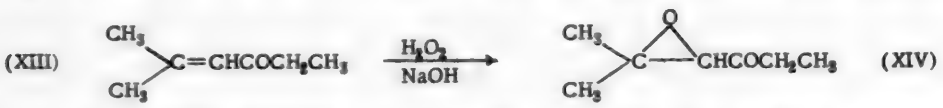


(X) (V)

Hydrolyzing the ketonic ether (V) with dilute sulfuric acid yielded the crystalline ketoglycol (XI):

(XI) (XII)

The hydrolysis reaction was paralleled, however, by the isomerization of the ketonic ether (V) to the well-known α-diketone (XII) [5]. Hydrogenation of the ketonic ether (V) with a palladium catalyst yielded the β-ketol (VI) described above. As in the case of mesityl oxide [1], the oxidation of ethyl isobutyl ketone (XIII) with alkaline hydrogen peroxide is not a smooth reaction, a low yield of the ketonic ether (XIV) being produced:



(XIII) (XIV)

In this reaction the formation of the ketonic ether (XIV) is paralleled by that of a high-boiling product with the empirical formula of $C_7H_{14}O_3$, an isomer of the ketoglycol.

EXPERIMENTAL

Preparation of the monoether of β,β-dimethyldivinyl ketone (III). A solution of 55 grams of β,β-dimethyl divinyl ketone (I) (b.p. 46° at 10 mm; n_D^{20} 1.4815) [4] in 500 ml of acetone was chilled to −10°, and 112 ml of 15% hydrogen peroxide (1 mole) and 8 ml of a 4 N aqueous solution of sodium hydroxide were added simultaneously from two dropping funnels in the course of 1 hour, with constant stirring and chilling. The solution temperature was kept at −10 to −6° by chilling the flask with a snow and salt mixture. One hour after the reagents had been added, the solution contained 1.13 g of hydrogen peroxide (17 g of hydrogen peroxide having been added). The alkali was neutralized with 10% sulfuric acid, the sodium sulfate was filtered out, pyrogallol was added, and the solvent was driven off in vacuo. The product was extracted with ether, dried with magnesium sulfate, and fractionated in vacuo after the ether had been driven off. This yielded 20 g of the monoether (III) as a colorless volatile liquid with a faint camphor odor.

B.p. 48.5-49° at 1 mm; n_D^{20} 1.4830; d_4^{20} 1.0247; MR_D 35.18; calculated 34.21.
8.680 mg substance: 21.16 mg CO_2; 6.24 mg H_2O. 10.950 mg substance: 26.60 mg CO_2; 7.98 mg H_2O.
0.1207 g substance; 12.0 g benzene: Δt 0.426°. 0.2829 g substance; 12.0 g benzene: Δt 0.967°.
Found %: C 66.49, 66.29; H 8.04, 8.15. M 123, 126. $C_7H_{10}O_2$. Calculated %: C 66.67; H 7.94; M 126.

The semicarbazone of the monoether (III) could not be recrystallized; it melted with decomposition at 132-133° after having been washed with methanol.

5.635 mg substance: 0.757 ml N_2 (22°, 752 mm). 7.473 mg substance: 1.021 ml N_2 (23°, 745 mm).
Found %: N 15.38, 15.45. $C_{15}H_{21}O_3N_3$. Calculated % N 14.43.

In another test, we secured, in addition to the monoether (III) 5 g of a fraction with a b.p. of 43-44° at 1.5 mm; n_D^{22} 1.4810, green in color with an acrid odor, which probably was the isomeric monoether (IV). It was not investigated any further.

The monoether (III) underwent no change when kept in a sealed container for a long time. It slowly thickened when exposed to the air, turning into a tacky polymer.

When the β,β-dimethyl divinyl ketone (I) was oxidized with alkaline hydrogen peroxide in dioxane, the yield of the monoether (III) dropped to 10%, about 10% of the previously described ketodiether (II) being produced, though the principal reaction product was a polymer.

Hydrogenation of the monoether (III). a) 6.3 g of the freshly distilled monoether (III) was dissolved in 40 ml of ethyl alcohol and hydrogenated with 0.1 g of a palladium catalyst on calcium carbonate. Hydrogenation set in immediately and continued at a rather high velocity, 1.28 liters of hydrogen being absorbed within 1 hour 15 minutes, after which hydrogenation was broken off. The coagulated catalyst was filtered out, the alcohol driven off, and the residue distilled in vacuo.

This yielded 1.8 g of the saturated ketonic ether (V) as a colorless, mobile liquid with a pleasant ethereal fragrance.

B.p. 67° at 12 mm; n_D^{20} 1.4340; d_4^{20} 0.9624 MR_D 34.57; calculated 34.68.
6.390 mg substance: 14.414 mg CO_2; 5.485 mg H_2O. 3.221 mg substance: 7.774 mg CO_2; 2.760 mg H_2O.
0.1408 g substance; 14.0 g benzene: Δt 0.392°. 0.3686 g substance; 14.0 g benzene: Δt 1.063°.
Found %: C 65.83, 65.86; H 9.60, 9.59. M 133, 128. $C_7H_{12}O_2$. Calculated %: C 65.63; H 9.37; M 128.

We were unable to recrystallize the semicarbazone of the ketonic ether (V). After it had been washed on the filter with methanol, it consisted of colorless crystals with a m.p. of 98° (decomp.).

3.350 mg substance: 0.677 ml N_2 (18°, 743 mm). 3.730 mg substance: 0.757 ml N_2 (21°, 742 mm).
Found %: N 22.82, 23.0. $C_8H_{15}O_2N_3$ Calculated %: N 22.70.

b) 8 grams of the monoether (III) was dissolved in 60 ml of ethyl alcohol and then hydrogenated for 7 hours with 0.15 g of a palladium catalyst. During the first hour and 15 minutes 2.5 liters of hydrogen was absorbed, after which hydrogenation slowed down considerably, only 0.1 liter of hydrogen being absorbed during the next 5 hours 45 minutes. A total of 2.6 liters of hydrogen was absorbed. The catalyst was filtered out, the alcohol driven off, and the product distilled in vacuo.

This yielded 2 grams of a fraction with a b.p. of 64.5-66° at 10 mm, corresponding to the ketonic ether (V) described above, plus 1.8 grams of a fraction of the β-ketol (VI) as a colorless liquid with a b.p. of 61° at 1 mm.

n_D^{20} 1.4352; d_4^{20} 0.9461; MR_D 35.87; calculated 36.06.

5.984 mg substance: 14.157 mg CO_2; 5.791 mg H_2O. 3.849 mg substance: 9.065 mg CO_2; 3.715 mg H_2O.
0.2167 g substance: 47.6 ml CH_4 (19°, 754 mm) by the Chugaev - Tserevitinov method.
Found %: C 64.56, 64.27; H 10.83, 10.80; OH 15, 29. $C_7H_{13}O(OH)$. Calculated %: C 64.62; H 10.77; OH 13.08.

It formed a dihydrazone with a m.p. of 145° (from ethyl alcohol) when reacted with 2,4-dinitrophenylhydrazine.

3.795 mg substance: 0.766 ml N_2 (23°, 755 mm). 3.800 mg substance: 0.777 ml N_2 (23°, 750 mm).
Found %: N 23.13, 23.27. $C_{19}H_{19}O_8N_8$. Calculated %: N 22.95.

Dehydration of the β-ketol (VI). 1.8 grams of the ketol (VI) was distilled in vacuo with 0.08 g of p-toluenesulfonic acid. About 1 gram of substance was distilled at 30° and 10 mm, which was dried and redistilled in vacuo, yielding about 0.2 g of vinyl isobutyl ketone (VII) (b.p. 29-30° at 10 mm; n_D^{18} 1.4280) a yellow liquid with an acrid odor and strong lachramatory effect [4].

When reacted with semicarbazide, this vinyl ketone yielded an addition product with a m.p. of 175-176° (from alcohol).

Hydrolysis of the monoether (III). a) 13.3 grams of the monoether (III) was left to stand overnight at room temperature with 130 ml of 3% sulfuric acid. The next day the mixture was heated to 70° for 8 hours and on a boiling water bath for 2 hours. A tar was seen to form. The solution was then saturated with potash and extracted with ether, the ether extracts being dried with magnesium sulfate.

One gram of crystals of the hydroxypyrone (IX) settled out of the anhydrous ether solution as minute, silky, white needles with a m.p. of 158° (from chloroform).

2.632 mg substance; 5.635 mg CO_2; 2.000 mg H_2O. 5.638 mg substance: 12.027 mg CO_2; 4.260 mg H_2O.
Found %: C 58.42, 58.21; H 8.50, 8.45. $C_7H_{12}O_3$. Calculated %: C 58.38; H 8.34.

The hydroxypyrone (IX) is very slightly soluble in anhydrous ether, petroleum ether, benzene, or dioxane, but freely soluble in water, ethyl alcohol, and methanol.

0.0486 g substance: 18.7 ml CH_4 (20°, 729.7 mm). 0.0662 g substance; 26.2 ml CH_4 (20°, 729.7 mm).
Found %: OH 25.32, 26.0. $C_7H_{10}O(OH)_2$. Calculated %: OH 23.60.

The hydroxypyrone (IX) forms no semicarbazone nor does it decolorize a chloroform solution of bromine (0°).

Driving off the ether yielded about 5 g of liquid hydrolysis products, which yielded 1 g of the ketoglycol (VIII) described above, with a b.p. of 97.5-98.5° at 1 mm; n_D^{19} 1.4965; and 2.5 g of a low-boiling product of unknown structure, with a b.p. of 57-58° at 1 mm; n_D^{21} 1.4624.

6.753 mg substance: 14.157 mg CO_2; 4.835 mg H_2O. 4.540 mg substance; 9.517 mg CO_2; 3.277 mg H_2O.
Found %: C 57.21, 57.21; H 8.01, 8.07. $C_7H_{12}O_3$. Calculated %: C 58.38; H 8.34.

b) A mixture of 5.3 g of the monoether (III) and 100 ml of distilled water (the two forming a stable emulsion) was heated on a boiling water bath for 7 hours. Driving off the water in vacuo yielded 3.5 g of a thick liquid, from which the unsaturated ketoglycol (VIII) was isolated as a thick, nearly colorless, odorless syrup with a b.p. of 103° at 2 mm by triple distillation.

n_D^{20} 1.4995; d_4^{20} 1.1081; MR_D 38.19; calculated 37.13.

7.165 mg substance: 15.158 mg CO_2; 5.350 mg H_2O. 7.244 mg substance: 15.373 mg CO_2; 5.516 mg H_2O. Found %: C 57.73, 57.91; H 8.35, 8.52. $C_7H_{12}O_3$. Calculated %: C 58.38; H 8.34.

The ketoglycol (VIII) rapidly decolorized a chloroform solution of bromine.

Oxidation of vinyl isobutyl ketone (X) by alkaline hydrogen peroxide. Synthesis of the ketonic ether (V). The vinyl isobutyl ketone employed in these experiments was prepared by splitting methanol out of 1-methoxy-5-methylhexan-3-one with p-toluenesulfonic acid as described earlier [7]; its constants were as follows: b.p. 41-42° at 22 mm; n_D^{15} 1.4293.

A solution of 95 g of vinyl isobutyl ketone (X) in 500 ml of dioxane was chilled to −6°, and 220 ml of a 15% solution of hydrogen peroxide (1 mole) and 10 ml of a 4 N aqueous solution of sodium hydroxide were added simultaneously from two dropping funnels during the course of 1 hour 20 minutes. Continuous stirring and chilling with a snow-salt mixture were used during the reaction. Considerable heat was evolved. After the reagents had been added, the reaction mixture contained 5 g of hydrogen peroxide (35 g of H_2O_2 having been added).

The residual hydrogen peroxide was decomposed with manganese dioxide, the alkali was neutralized with 10% sulfuric acid, the precipitated sodium sulfate was filtered out, the solvent was driven off in vacuo, and the products were extracted with ether, dried with sodium sulfate, and fractionated in vacuo. This yielded 69 g of a substance with a b.p. of 75-79° at 22 mm, further fractionation of which yielded 50 g of the ketonic ether (V) described above, as faintly odorous, colorless, mobile liquid with a b.p. of 77° at 22 mm; n_D^{20} 1.4303.

6.468 mg substance: 15.432 mg CO_2; 5.688 mg H_2O. 4.820 mg substance: 11.654 mg CO_2; 4.350 mg H_2O. Found %: C 65.11, 65.02; H 9.84, 9.95. $C_7H_{12}O_2$. Calculated %: C 65.63; H 9.37.

10 grams of this ketonic ether was dissolved in 40 ml of ethyl alcohol and hydrogenated with a palladium catalyst; 1.3 liters of hydrogen was absorbed during 10 hours, after which hydrogenation was stopped. This yielded 3 g of the β-ketol (VI) as a colorless liquid.

B.p. 73-73.5° at 4 mm; n_D^{20} 1.4318.

3.930 mg substance: 9.340 mg CO_2; 3.868 mg H_2O. 5.600 mg substance; 13.248 mg CO_2; 5.448 mg H_2O. Found %: C 64.85, 64.57; H 11.0, 10.89. $C_7H_{14}O_2$. Calculated %: C 64.62; H 10.77.

Reaction with 2,4-dinitrophenylhydrazine yielded a dihydrazone as yellow crystals with a m.p. of 124° (from alcohol).

4.035 mg substance: 1.029 ml N_2 (21°, 735 mm). 5.010 mg substance: 1.043 ml N_2 (22°, 736 mm). Found %: N 23.41, 23.33. $C_{19}H_{20}O_8N_8$. Calculated %: N 22.95.

Hydrolysis of the ketonic ether (V). 19.5 g of the ketonic ether (V) was boiled for 20 hours with 230 ml of 2% sulfuric acid. A layer of a brown liquid formed on the surface of the water. The oily layer was removed, and the solution was neutralized with sodium bicarbonate and evaporated in vacuo. The product was extracted with ether, dried with magnesium sulfate, and filtered, after which the ether was driven off.

4.718 mg substance: 9.926 mg CO_2; 4.042 mg H_2O. 4.829 mg substance; 10.172 mg CO_2; 4.060 mg H_2O. 0.0748 g substance: 27.7 ml CH_4 (24°, 756 mm) by the Chugaev-Tserevitinov method. 0.2235 g substance: 16.0 g dioxane: Δt 0.444°. 0.3238 g substance; 16.0 g dioxane: Δt 0.657°. Found %: C 57.41, 57.48; H 9.58, 9.41; OH 25.48. M 142, 145. $C_7H_{12}O(OH)_2$. Calculated %; C 57.53; H 9.59; OH 23.29; M 146.

3.5 grams of the thinnest silvery-white flakes of the ketonic glycol (XI) settled out of the ether solution; its m.p. was 71-72° after recrystallization from petroleum ether.

The semicarbazone of the ketoglycol (XI) was not found.

Recovery of the α-diketone (XII). The separated oily layer was dissolved in ether and dried with magnesium sulfate. The ether was driven off, the residue distilled in vacuo; yield 6 g of a substance with b.p. 46-48° at 20 mm.

Distillation at standard pressure yielded 5 g of the α-diketone (XII) as a mobile yellow liquid with b.p. 138-139°.

n_D^{20} 1.4119; d_4^{20} 0.9135; MR_D 34.86. Calculated 34.55.

The α-diketone (XII) readily forms a dioxime: lustrous white leaflets with m.p. 172-173° (from dilute alcohol).

3.985 mg substance: 0.617 ml N_2 (25°, 744 mm). 4.005 mg substance: 0.632 ml N_2 (25°, 743 mm).
Found %: N 17.36, 17.67. $C_7H_{14}O_2N_2$. Calculated %: N 17.70.

The boiling point of the α-diketone (XII) is given as 138° in the literature [6], its dioxime fusing at 168°.

Oxidation of ethyl isobutenyl ketone (XIII) with alkaline hydrogen peroxide. The ethyl isobutenyl ketone employed in these experiments was prepared by partially hydrogenating β,β-dimethyl divinyl ketone as described previously [7]; its constants were as follows: 146-147°; n_D^{20} 1.4420.

4 g of ethyl isobutenyl ketone (XIII) was dissolved in 55 ml of methanol and chilled and continuously stirred while 9 ml of a 15% solution of hydrogen peroxide (1 mole) and 2.5 ml of a 4 N solution of sodium hydroxide were added simultaneously from two dropping funnels in the course of 15 minutes. Considerable heat was evolved. The reaction mass contained 0.4 g of hydrogen peroxide (1.35 g of hydrogen peroxide had been added initially) 45 minutes after the reagents had been added to the reaction mixture. The solution was neutralized with 10% sulfuric acid, the excess hydrogen peroxide was decomposed with manganese dioxide, the solution was diluted with twice its volume of water, and the products were extracted with ether. The ether extracts were dried with magnesium sulfate, the ether was driven off, and the residue was distilled in vacuo. This yielded a small amount of the ketonic ether (XIV) as a colorless liquid with b.p. of 77-78° at 21.5 mm; n_D^{20} 1.4315.

4.560 mg substance: 10.792 mg CO_2; 3.900 mg H_2O. 4.460 mg substance: 10.563 mg CO_2; 3.800 mg H_2O.
Found %: C 64.58, 64.63; H 9.57, 9.53. $C_7H_{12}O_2$. Calculated %: C 65.63; H 9.37.
The ketonic ether (XIV) does not form a semicarbazone.

In addition to the ketonic ether (XIV), this experiment also yielded a small quantity of a substance with b.p. 63° at 4 mm; n_D^{21} 1.4365, which was, probably, a compound that was isomeric with the ketoglycol as had been the case in the oxidation of mesityl oxide [1].

9.80 mg substance: 21.12 mg CO_2; 8.51 mg H_2O. 20.49 mg substance: 44.18 mg CO_2; 17.35 mg H_2O.
Found %: C 58.61, 58.84; H 9.71, 9.60. $C_7H_{14}O_3$. Calculated %: C 57.53; H 9.59.

This product was not investigated any further.

SUMMARY

When one molecule of alkaline hydrogen peroxide is reacted with β,β-dimethyl divinyl ketone (I), the oxygen is added chiefly at the unsubstituted vinyl group, producing a 40% yield of the unsaturated monoether (III). Hydrogenation of the monoether (III) yields the saturated ketonic ether (V), which was also synthesized, with a yield of 60%, by oxidizing vinyl isobutyl ketone with alkaline hydrogen peroxide.

Exhaustive hydrogenation of the monoether (III) with a palladium catalyst ruptures the oxide ring and yields the β-ketol (VI), which was also synthesized by hydrogenation of the ketonic ether (V). Hydrolyzing the unsaturated monoether (III) with 3% sulfuric acid yields 2,2-dimethyl-5-hydroxytetrahydro-4-pyrone (IX), while hydrolysis with water yields the unsaturated ketoglycol (VIII). When the ketonic ether (V) is heated with 2% sulfuric acid, the normal hydrolysis reaction and the formation of the ketoglycol (XI) are paralleled by the isomerization of the ketonic ether (V) to the well-known α-diketone (XII). As in the case of mesityl oxide, the oxidation of ethyl isobutenyl ketone (XIII) with alkaline hydrogen peroxide is a less smooth reaction, a low yield of the ketonic ether (XIV) being produced.

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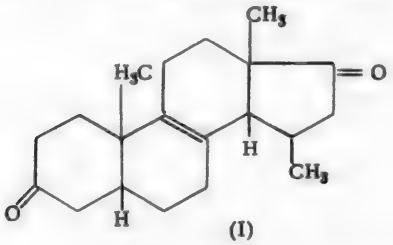
133. SYNTHESIS OF POLYCYCLIC COMPOUNDS RELATED TO THE STEROIDS

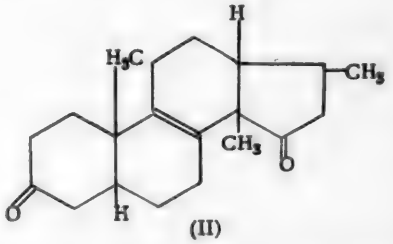
X. THE DIENE CONDENSATION OF 2-METHOXY-1,3-BUTADIENE WITH Δ^1-CYCLOHEXEN-6-ONE

I. N. Nazarov and L. D. Bergelson

In one of our preceding reports [1] we described the diene condensation of 2-methoxy-1,3-butadiene with 1-methyl-Δ^1-cyclohexen-6-one, which resulted in the complete synthesis of the stereoisomer (I) or of the structural isomer (II) of $\Delta^{8,9}$-15-methylandrostene-3,17-dione:

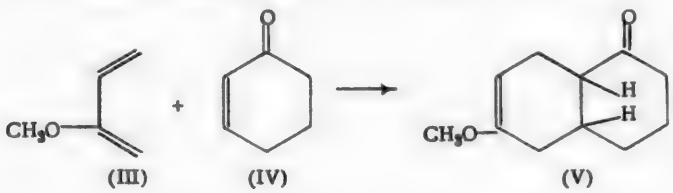


(I)



(II)

We were interested in effecting a similar condensation of 2-methoxybutadiene (III) with Δ^1-cyclohexen-6-one (IV) since the resultant cis-6-methoxyoctalone (V) is not only a model compound enabling one to study the stereochemical behavior patterns of diene condensation, but might also serve as an intermediate in the synthesizing of norsteroid compounds with cis and trans configurations of the A/B rings.



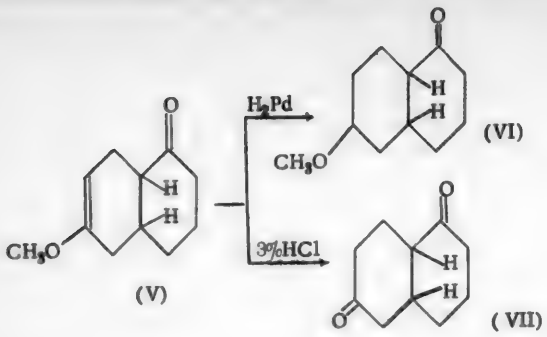
(III) (IV) (V)

Like the condensations with other α,β-unsaturated cyclic ketones, a satisfactory yield can be obtained in the condensation of the methoxybutadiene (III) with Δ^1-cyclohexen-6-one (IV) only at 190-200° in a solution containing a large excess of the ketone, since the predominant reaction is the dimerization of the methoxybutadiene when the conditions are milder or the dilution is insufficient. It is also advisable to carry out the reaction in an atmosphere of nitrogen or carbon dioxide with antioxidants present. Under these conditions the yield of 6-methoxyoctalone (V) may be made as high as 15-20%, based on the reacted cyclohexenone.

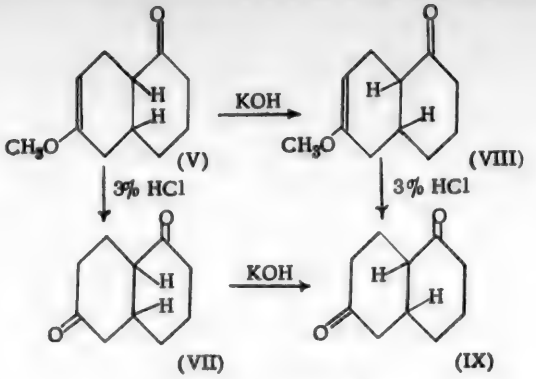
As with other enolic ethers, methoxyoctalone (V) is hydrogenated in ether only when a Pd catalyst is present, being converted then into 6-methoxydecalone (VI). Hydrolysis of the cis-methoxyoctalone (V) with dilute solutions of mineral acids produces a nearly quantitative yield, even in the cold, of the crystalline cis-1,6-diketodecalin (VII) (see Scheme A on following page).

The action of an alkali upon cis-methoxyoctalone (V) readily isomerizes it to trans-methoxyoctalone (VIII), which is hydrolyzed by dilute mineral acids to the high-melting trans-1,6-diketodecalin (IX). This same diketone may be prepared from the low-melting cis-1,6-diketodecalin (VII) by heating the latter with an alcoholic alkali (see Scheme B on following page).

The rules established by Huckel [2] for the α-decalone series indicate that the low-melting diketodecalin (VII) and the corresponding methoxyoctalone (V), as well as the methoxydecalone (VI), must have cis configurations.



Scheme A

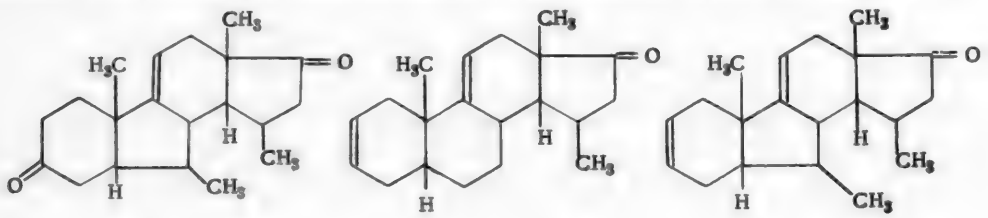


Scheme B

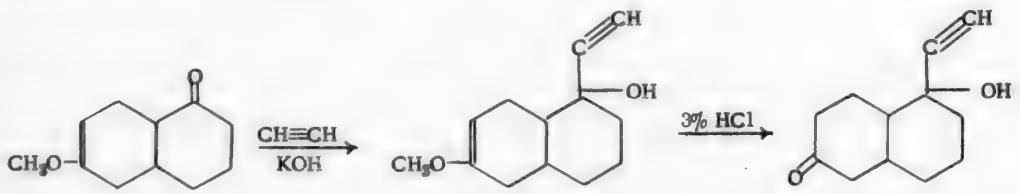
The high melting diketone (IX) and methoxyoctalone (VIII) must, accordingly, be trans isomers. It is worthy of note that the isomeric 1,6-diketodecalins (VII) and (IX) yield the same disemicarbazone of the trans isomer. An analogous phenomenon has been observed in similar cases [2,3,4].

In 1937 Alder and Stein [5] advanced the hypothesis, on the basis of their investigation of the diene condensation of butadiene with benzoquinone and of cyclopentadiene with maleic anhydride, that the diene synthesis always results in a cis addition compound. In the present paper, we prove for the first time that this postulate also applies to diene condensations with α,β-unsaturated cyclic ketones.

These findings of ours also indicate that the A/B and C/D rings in the steroid compounds (I, X, XI, and XII) synthesized in our laboratory by diene condensations are joined together in the cis position [1,6,7]:



In contrast to other cyclic ketones, the methoxyoctalone (V) is condensed only with difficulty with acetylene when powdered potassium hydroxide is present, only a minute yield of 1-ethynyl-6-methoxyoctalol (XIII) being obtained. This acetylenic methoxyoctalol can be hydrolyzed in the cold by dilute mineral acids, yielding the acetylenic ketodecalol (XIV).



We propose to utilize the acetylenic alcohols (XIII) and (XIV) to synthesize compounds with the skeleton of 10-norandrostane.

EXPERIMENTAL

Diene condensation of 2-methoxy-1,3-butadiene with Δ^1-cyclohexen-6-one. These experiments were performed in a metallic ampoule in an atmosphere of nitrogen or carbon dioxide. Vacuum fractionation was performed in a current of anhydrous air.

a) 86 g of the Δ^1-cyclohexenone was heated with 28 g of 2-methoxybutadiene to 190-200° for 5 hours. Fractionation yielded 55 g of the initial cyclohexenone, 7.3 g of the dimer of 2-methoxybutadiene [8], and 16 g of condensation products with a b.p. of 120-139° at 4 mm. Refractionation of the last fraction yielded 8.5 g of

Δ^6-cis-6-methoxy-1-octalone (V) as a viscous yellow oil with a faint camphor odor, a b.p. of 96-98° at 0.1 mm, and of 129.5-132° at 4 mm; n_D^{20} 1.5063.

b) [illegible] the Δ^1-cyclohexenone was heated to 185-190° for 25 hours with 10 g of 2-methoxybutadiene in 15 ml of absolute dioxane. Fractionation yielded 30 g of the initial cyclohexenone, 3.5 g of the dimer of the methoxybutadiene, and 2.8 g of the methoxyoctalone (V) with a b.p. of 128-132° at 4.5 mm; n_D^{20} 1.5040.

Analysis of the Δ^6-cis-6-methoxy-1-octalone (V) (from Experiment a):
7.875 mg substance: 21.228 mg CO_2; 6.097 mg H_2O. 4.575 mg substance: 12.297 mg CO_2; 3.540 mg H_2O.
Found %: C 73.5, 73.3; H 8.7, 8.7. $C_{11}H_{16}O_2$. Calculated %: C 73.3; H 8.9.

When the methoxyoctalone was reacted with semicarbazide acetate in absolute methanol, the water evolved saponified the vinyl ether, the monosemicarbazone of trans-1,6-diketodecalin (IX), m.p. 227° (from alcohol) settling out.

3.560 mg substance: 0.584 ml N_2 (20°, 749 mm). 3.210 mg substance: 0.523 ml N_2 (20°, 748 mm).
Found %: N 18.8, 18.7: $C_{11}H_{17}O_2N_3$. Calculated %: N 18.8.

Hydrogenation of cis-Δ^6-6-methoxy-1-octalone (V). 2.4 g of the 6-methoxyoctalone was hydrogenated in absolute ether with a Pd catalyst, 245 ml of hydrogen being absorbed in 8 hours (280 ml called for theoretically). Fractionation yielded 2.1 g of cis-6-methoxy-1-decalone (VI); b.p. 124° at 5 mm; n_D^{20} 1.4987.

5.878 mg substance: 15.700 mg CO_2; 5.257 mg H_2O. 5.112 mg substance: 13.650 mg CO_2; 4.565 mg H_2O.
Found %: C 72.9, 72.8; H 10.0, 10.0. $C_{11}H_{18}O_2$. Calculated %: C 72.5; H 10.0.

Practically no hydrogen was absorbed when the 6-methoxyoctalone (V) was hydrogenated in ethyl alcohol with a Pd catalyst.

Hydrolysis of cis-Δ^6-6-methoxy-1-octalone (V). 5 g of the methoxyoctalone (V) was agitated for 3 hours at room temperature with 20 ml of 3% hydrochloric acid. The mixture was then saturated with ammonium chloride the organic layer being removed, the aqueous layer extracted with ether, and the combined ether solutions neutralized with a 5% soda solution and dried with magnesium sulfate. Driving off the ether left behind a solid mass. Recrystallization from benzene yielded 3.9 g of cis-1,6-diketodecalin (VII) as colorless lamellar crystals with a m.p. of 87-88°.

3.710 mg substance: 9.812 mg CO_2; 2.820 mg H_2O: 6.698 mg substance: 17.662 mg CO_2; 5.090 mg H_2O.
Found %: C 72.2, 72.0; H 8.5, 8.5. $C_{10}H_{14}O_2$. Calculated %: C 72.3; H 8.5.

The disemicarbazone of the synthesized diketone was insoluble in organic solvents. After having been washed repeatedly with ether and alcohol it fused with decomposition at 243-244° (in a sealed capillary).

3.180 mg substance: 0.828 ml N_2 (19°, 744 mm). 3.750 mg substance: 0.982 ml N_2 (21°, 749 mm).
Found %: N 29.8, 30.0. $C_{12}H_{20}O_2N_6$. Calculated %: N 30.0.

Isomerization of cis-1,6-diketodecalin (VII). 0.4 g of cis-1,6-diketodecalin (m.p. 87°) was heated to a boil with 35 ml of 10% alcoholic alkali for 3 hours. Most of the alcohol was driven off, and the residue diluted with water and extracted with ether, the ether extract being neutralized with acetic acid and dried with magnesium sulfate. Driving off the ether left behind 0.25 g of the acicular crystals of trans-1,6-diketodecalin (IX), which had a m.p. of 125-126° after recrystallization from benzene.

4.300 mg substance: 11.380 mg CO_2; 3.320 mg H_2O. 5.290 mg substance: 14.050 mg CO_2; 4.100 mg H_2O.
Found %: C 72.2, 72.4; H 8.6, 8.6. $C_{10}H_{14}O_2$. Calculated %: C 72.3; H 8.5.

The disemicarbazone of trans-1,6-diketodecalin (IX) fused at 243° with decomposition. The mixed melting point with the disemicarbazone prepared from the cis-diketodecalin (VII) showed no depression.

Isomerization of cis-Δ^6-6-methoxy-1-octalone (V). Trans-Δ^6-6-methoxy-1-octalone (VIII) was recovered in one of our attempts to condense the cis-methoxyoctalone (V) with acetylene in the presence of powdered potassium hydroxide.

8 grams of the cis-methoxyoctalone (V) was placed in 40 ml of absolute ether, and 4 g of powdered potassium hydroxide and 80 ml of ether, previously chilled to -15° and saturated with acetylene, were added drop by drop in a current of acetylene during the space of one hour and a half. Acetylene was passed through for another hour and a half with chilling and stirring, and then for two more hours at room temperature. 10 ml of water was added to the mixture, the ether was separated, the aqueous layer extracted with ether, and the combined ether solutions

neutralized by passing carbon dioxide through and then dried with potash. Fractionation yielded 5.4 g of trans-Δ^6-6-methoxy-1-octalone (VIII), with a b.p. of 123° at 4.5 mm; n_D^{20} 1.5010.

4.130 mg substance: 11.112 mg CO_2; 3.225 mg H_2O. 5.177 mg substance: 13.895 mg CO_2; 4.020 mg H_2O. Found %: C 73.4, 73.3; H 8.7, 8.7. $C_{11}H_{16}O_2$. Calculated %: C 73.3; H 8.9.

5 grams of the trans-6-methoxy-1-octalone was agitated for 3 hours with 20 ml of 3% hydrochloric acid. Then the mixture was saturated with ammonium chloride and extracted with ether, and the ether solution neutralized with a 5% soda solution and dried with magnesium sulfate. Driving off the ether left behind 4.2 g of colorless crystals that fused at 124-125° (from benzene). The mixed melting point with trans-1,6-diketodecalin exhibited no depression.

Condensation of cis-Δ^6-6-methoxy-1-octalone (V) with acetylene. A solution of 3 g of the cis-6-methoxy-octalone (V) in 10 ml of absolute ether was added, with vigorous stirring, in a current of acetylene during the course of 2 hours to a mixture of 2.3 g of powdered potassium hydroxide and 20 ml of ether that had been previously chilled to −15° and saturated with anhydrous acetylene. The acetylene was then passed through for 2 hours while the mixture was chilled, and for 12 hours the next day at room temperature. 10 ml of water was added to the solidified mixture, the ether layer was separated, the aqueous layer extracted with ether, and the combined ether solutions neutralized by passing through carbon dioxide, dried with potash, and vacuum-fractionated in a current of anhydrous nitrogen. This yielded 1.0 g of 1-ethynyl-6-methoxy-1-octalol (XIII) (b.p. 112-115° at 0.05 mm) as a thick colorless mass that slowly crystallized upon standing and yielded a white precipitate with ammoniacal silver nitrate. After recrystallization from petroleum ether the crystals had a m.p. of 62-64.5°, the m.p. rising to 69-71° after drying in vacuo over phosphoric anhydride (they totaled 0.6 g).

4.310 mg substance: 11.947 mg CO_2; 3.510 mg H_2O. 5.880 mg substance: 16.240 mg CO_2; 4.790 mg H_2O. Found %: C 75.6, 75.4; H 9.1, 9.1. $C_{13}H_{18}O_2$. Calculated %: C 75.7; H 8.8.

Hydrolysis of Δ^6-1-ethynyl-6-methoxy-1-octalol (XIII). The mother liquor left after the recrystallization of the acetylenic alcohol (XIII) was agitated for 3 hours at room temperature with 10 ml of 3% hydrochloric acid. The mixture was then saturated with ammonium chloride and extracted with ether, the ether layer being neutralized with a 5% soda solution and dried with magnesium sulfate. After the ether had been driven off, a solution of semicarbazide acetate in methanol (a threefold excess) was added to the residue. The semicarbazone that settled out after 15 days was separated in a soluble fraction and a fraction that was insoluble in hot methanol. The methanol-insoluble crystals fused at 239-241° in a sealed capillary (with decomposition), their mixed melting point with the disemicarbazone of the 1,6-diketodecalin exhibiting no depression. The crystals of the soluble fraction, which had a m.p. of 251-253° (with decomposition) after recrystallization from alcohol, were the semicarbazone of 1-ethynyl-6-ketodecalol (XIV).

3.200 mg substance: 0.478 ml N_2 (20°, 740 mm). 3.200 mg substance: 0.473 ml N_2 (19°, 740 mm). Found %: N 17.0, 16.8. $C_{13}H_{19}O_2N_3$. Calculated %: N 16.9.

SUMMARY

1. Δ^6-6-Methoxy-1-octalone (V), an intermediate product in the preparation of steroid compounds with the skeleton of 10-norandrostane, has been synthesized.

2. It has been shown that the diene condensations with α,β-unsaturated ketones result in cis addition compounds.

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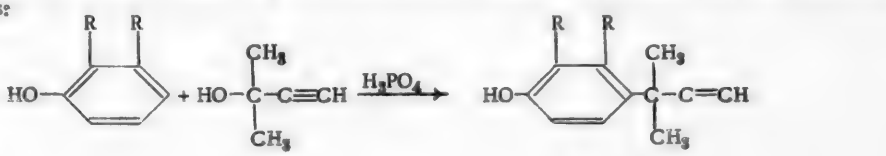
134. THE CONDENSATION OF TETRAMETHYLBUTYNEDIOL AND 2,5-DIMETHYL-1-5-HEXADIEN-3-YNE WITH PHENOL IN THE PRESENCE OF PHOSPHORIC ACID

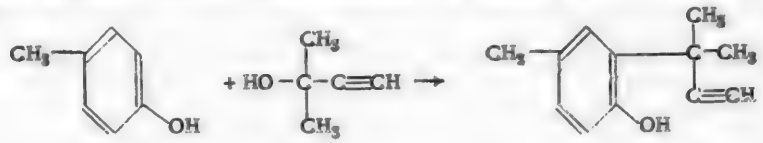
I. N. Nazarov and A. I. Kakhniashvili

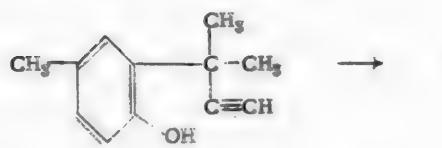
The condensation of phenol and of the cresols with acetylenic and vinyl acetylenic alcohols was investigated for the first time by I. N. Nazarov and his associates [1]. The condensation was effected in the presence of phosphoric acid, producing a yield of some 50% of para-substituted phenols and cresols of the acetylenic and vinylacetylenic series:

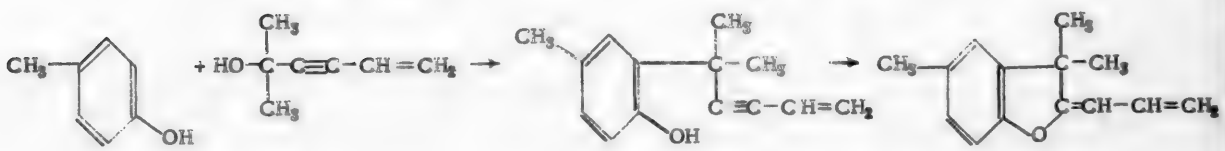


R = H or CH_3.

The same products are secured by condensing phenol and the cresols with the respective unsaturated hydrocarbons produced by dehydrating the acetylenic and vinylacetylenic alcohols. The condensation of acetylenic and vinylacetylenic alcohols with p-cresol results in the formation of an intermediate ortho-substituted cresol of acetylenic or vinylacetylenic structure, which is cyclized completely to methylene- or allylidenecoumarans under the reaction conditions.

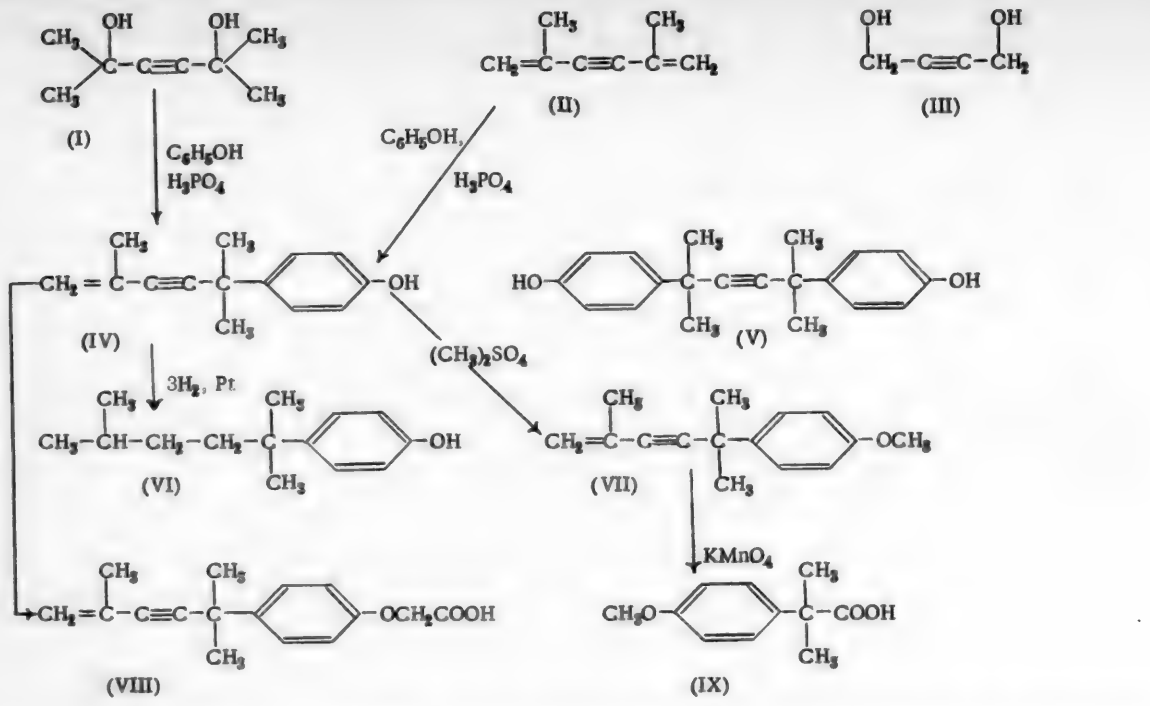




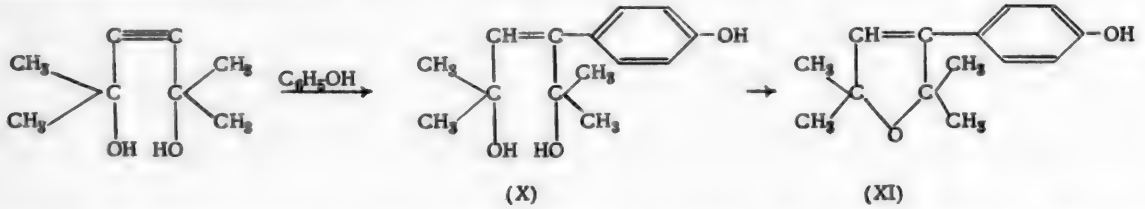


We were also interested in investigating the condensation of phenols with acetylenic glycols, and we used for this purpose the simplest representatives of primary and tertiary acetylenic γ-glycols – tetramethylbutynediol (I) and 2-butyne-1,4-diol (III).

Condensing phenol with tetramethylbutynediol (I) at 45-50° in the presence of phosphoric acid yielded two phenolic products, which proved to be 2,5-dimethyl-5-p-hydroxyphenyl-1-hexen-3-yne (IV) and 2,2,5,5-tetramethyl-3-p-hydroxyphenyl-Δ^3-dihydrofuran (XI):

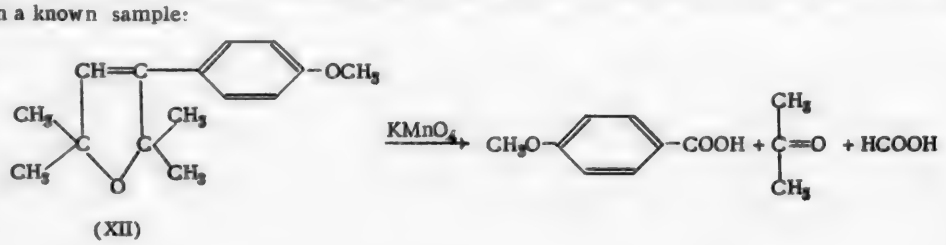


When the vinylacetylenic phenol (IV) was hydrogenated with a Pd catalyst, it absorbed the three molecules of hydrogen called for by the theory, yielding 2,5-dimethyl-5- p-hydroxyphenylhexane (VI). Methylating the vinylacetylenic phenol (IV) with dimethylsulfate yielded its methyl ester (VII), while reacting the vinylacetylenic phenol (IV) with chloroacetic acid yielded the corresponding crystalline phenoxyacetic acid (VIII). The structure of the vinylacetylenic phenol (IV) was conclusively proved by oxidizing its methyl ester (VII) with permanganate. This yielded, in addition to formic and acetic acids, a high yield of dimethyl-p-methoxyphenylacetic acid (IX), whose mixed melting point with a known sample exhibited no depression. It might have been thought that the condensing of phenol with tetramethylbutynediol would yield an acetylenic diphenol (V) in addition to the vinylacetylenic phenol (IV), but we have not been able to isolate that compound. The furanic phenol (XI) is most likely formed by the addition of phenol at the triple bond of the tetramethylbutynediol, followed by cyclization of the resultant intermediate ethylenic glycol (X):



Zalkind and his co-workers [2] have observed a similar trend of the reaction when phenol was condensed with tetraphenylbutynediol.

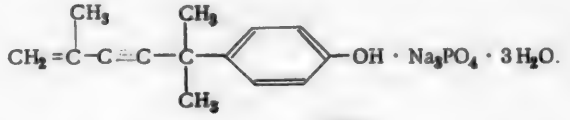
When the furanic phenol (XI) is methylated with dimethyl sulfate, we get its methyl ester (XII), the oxidation of which with permanganate yields acetone, formic acid, and anisic acid, which was identified by its mixed melting point with a known sample:



When phenol was condensed with 2,5-dimethyl-1,5-hexadien-3-yne (II) under the conditions specified above, all we got was the vinylacetylenic phenol (IV), none of the furanic phenol (XI) being formed, which bears out the mechanism proposed above for its formation. Nor were we able to secure the acetylenic diphenol (V) during this condensation, which might have been formed by the condensation of the dienyne (II) with two molecules of phenol.

Thus, the condensation of phenol with tetramethylbutynediol (I) in the presence of phosphoric acid follows two lines: 1) dehydration of the acetylenic glycol (I) to a dienyne (II), followed by condensation of this dienyne with phenol into the para-substituted vinylacetylenic phenol (IV); and 2) the addition of phenol at the triple bond of the acetylenic glycol (I) followed by cyclization of the ethylenic glycol (X) to the furan compound (XI). The first reaction line, resulting in formation of the vinylacetylenic phenol (IV), predominates.

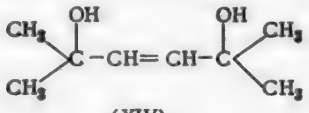
We have secured a crystalline phosphorus-containing product (XIII) (m.p. 137-139°) from the alkaline extracts of the condensation products of phenol with the acetylenic glycol (I) and with the dienyne (II), the analysis of this product indicating that it was a double compound of sodium phosphate hydrate with the vinylacetylenic phenol (IV):



(XIII)

All our attempts to condense phenol with butynediol (III) met with failure, notwithstanding the wide range of experimental conditions employed. When gentle conditions were used (45-50° and phosphoric acid with a sp. gr. of 1.7), all the phenol and much of the butynediol were recovered unchanged, while when the conditions used were severe (60-80° and a phosphoric acid of 1.82 sp. gr.), nearly all the butynediol turned into tar. These results indicate that phenol can be condensed with tertiary acetylenic glycol much more easily than with primary compounds, as has also been observed in the condensation of phenols with saturated alcohols and glycols.

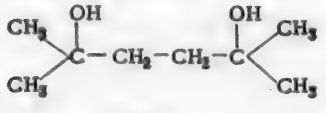
Lastly, we tried to condense phenol with tetramethylbutenediol (XIV) and tetramethyldihydrofuran (XV), but no condensation products at all were obtained.



(XIV)

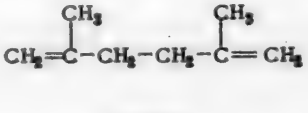
(XV)

When the ethylenic glycol (XIV) is heated with phenol in the presence of an acid (phosphoric or sulfuric), it is readily converted into the dihydrofuran (XV), which is either recovered unchanged or turns into tar. In this connection, it is worthy of note that tetramethylbutanediol (XVI) and the corresponding furan (XVII) and diene (XVIII) condense readily with benzene and the phenols in the presence of aluminum chloride, sulfuric acid, or boron trifluoride, yielding bicyclic and tricyclic compounds (methylated tetralins and indans, and the corresponding phenolic compounds) [3].



(XVI)

(XVII)



(XVIII)

EXPERIMENTAL

Tetramethylbutynediol (I) was prepared by condensing acetylene with acetone in the presence of powdered potassium hydroxide; its m.p. was 92-94°. The 2,5-dimethyl-1,5-hexadien-3-yne was prepared by dehydrating tetramethylbutynediol with p-toluenesulfonic acid; its b.p. was 124-126°; n_D^{20} 1.4874.

Condensation of tetramethylbutynediol with phenol in the presence of phosphoric acid. 71 g of tetramethylbutynediol (I) was gradually added at 50°, with continuous stirring, to a mixture of 47 g of freshly distilled phenol and 26 ml of phosphoric acid (sp. gr. 1.704). The mixture was stirred at 45-55° for 15 hours. After it cooled, the product was extracted with ether, the ether extract being washed with water and then several times with a 10% solution of sodium hydroxide to extract the acid reaction products. The alkaline extracts were combined and acidulated with dilute hydrochloric acid, and the product was extracted with ether. The ether solution was dried with potash, and after the ether had been driven off, the residual acid products were distilled in vacuo in an atmosphere

of nitrogen. This yielded 18 g of the unreacted phenol (b.p. 62-68° at 4 mm), 22 g of the substituted vinylacetylenic phenol (IV) (b.p. 132-138° at 4 mm; n_D^{20} 1.5505), and 10 g of the furanic phenol (XI) (b.p. 152-162° at 3 mm; n_D^{20} 1.5456). The polymer residue left after fractionation of the acid products totaled 22 g.

Fractionation of the ether solution containing the neutral products yielded 2 g of 2,5-dimethyl-1,5-hexadien-3-yne, (II), with a b.p. of 44-48° at 43 mm and 123-124° at atmospheric pressure; n_D^{20} 1.4872. We also secured 2.7 g of a mixture of high-boiling neutral products (b.p. 72-150° at 6 mm), which was not analyzed further. The polymer residue left after fractionation of the neutral products totaled 10 g.

Analysis of the vinylacetylenic phenol (IV). After the vinylacetylenic phenol (IV) had been refractionated it was a yellowish liquid with a b.p. of 126-129° at 2 mm;

n_D^{20} 1.548; d_4^{20} 0.9956; MR_D 63.8; calculated 62.32.

6.500 mg substance: 19.942 mg CO_2; 4.880 mg H_2O. 5.810 mg substance; 17.754 mg CO_2; 4.411 mg H_2O.
0.1866 g substance; 22.28 g benzene: Δt 0.213°. 0.2162 g substance; 22.28 g benzene: Δt 0.233°.
Found %: C 83.72, 83.5; H 8.40, 8.49; M 200.5, 210.4. $C_{14}H_{18}O$. Calculated %: C 84.0; H 8.0; M 200.
0.0829 g substance: 12 ml CH_4 (21°, 730 mm). Found %: OH 8.36. $C_{14}H_{18}OH$. Calculated %: OH 8.5.

The vinylacetylenic phenol (IV) distilled without decomposition in a nitrogen atmosphere and dissolved in a 10%solution of sodium hydroxide, alcohol, ether, acetone, chloroform, or benzene. It did not react with ferric chloride in either an aqueous or an alcoholic medium.

Analysis of the furanic phenol (XI): The fraction with a b.p. of 152-162° at 3 mm began to crystallize within a few days. Recrystallization of the product from ligroin yielded white crystals of the furanic phenol (XI) with a m.p. of 76-77°, which were soluble in alcohol, ether, petroleum ether, chloroform, and alkali.

4.230 mg substance: 11.979 mg CO_2; 3.316 mg H_2O. 4.012 mg substance: 11.358 mg CO_2; 3.081 mg H_2O.
Found %: C 77.3, 77.26; H 8.77, 8.63. $C_{14}H_{18}O_2$. Calculated %: C 77.06, H 8.25.

The liquid portion of the substance was redistilled (b.p. 156-160° at 3 mm) and analyzed:

6.675 mg substance: 19.002 mg CO_2; 5.150 mg H_2O. 7.285 mg substance: 20.705 mg CO_2; 5.523 mg H_2O.
0.1696 g substance; 15.33 g benzene: Δt 0.25°. 0.0796 g substance; 15.94 g benzene: Δt 0.116°.
Found %: C 77.68, 77.58; H 8.63, 8.48. M 225.6, 219.5. $C_{14}H_{18}O_2$. Calculated %: C 77.06; H 8.25; M 218.

Condensation of the vinylacetylenic phenol (IV) with chloroacetic acid. 1 g of the substituted phenol (IV) was dissolved in 10 ml of a 10% solution of sodium hydroxide, 1.5 g of chloroacetic acid was added, and the mixture was heated on a boiling water bath for 1.5 hours. Then the liquid was acidified and extracted with ether, the ether extract being washed with a weak soda solution, and the resultant alkaline extract acidulated with dilute sulfuric acid. The precipitated acid (VIII) was filtered out; its m.p. was 80-81.5° after recrystallization from aqueous alcohol.

6.480 mg substance: 17.769 mg CO_2; 4.173 mg H_2O. 6.309 mg substance: 17.226 mg CO_2; 4.000 mg H_2O.
0.0436 g substance; 17 ml 0.01 N NaOH: 0.0186 g substance; 7.5 ml 0.01 N NaOH.
Found %: C 74.83, 74.52; H 7.25, 7.09. M 256.4, 248. $C_{16}H_{18}O_3$. Calculated %: C 74.42; H 6.98. M 258.

Condensation of 2,5-dimethyl-1,5-hexadien-3-yne with phenol. 19 g of 2,5-dimethyl-1,5-hexadien-3-yne was added drop by drop, with constant stirring, at 50° to a mixture of 18 g of phenol and 11 ml of phosphoric acid (sp. gr. 1.71). The liquid was heated to 45-50° for 15 hours and then processed as in the preceding experiment. The acid reaction products yielded 6.5 g of unreacted phenol (b.p. 60-65° at 4 mm) and 7.5 g of the substituted vinylacetylenic phenol (IV) with a b.p. of 126-129° at 2 mm (the polymer residue totaling 12 g). The product of the reaction of this phenol with chloroacetic acid had a melting point of 80-81°, and its mixed melting point with the preceding sample exhibited no depression.

The ether solution of the neutral products yielded 1 g of the initial substance (b.p. 45-49° at 4 mm) and 1 g of a substance with a b.p. of 105-146° at 5 mm; n_D^{20} 1.5407. The polymer residue totaled 1 g.

A crystalline, phosphorus-containing substance could be recovered from the condensation products of phenol with both the tetramethylbutynediol (I) and the dienyne (II) by the following procedure: The ether solution of the condensate was extracted with alkali, and the alkaline solution was acidulated with a dilute solution of hydrochloric acid, the resulting oily substance being separated from the water and a small amount of ether added to it. White crystals settled out, which had a m.p. of 137-139° (with decomposition) after recrystallization from aqueous alcohol. When the substance was calcined, a mineral residue was left behind; reacting an aqueous solution of this residue with uranyl yielded a white precipitate, evidence of the presence of sodium.

3.904 mg substance: 5.770 mg CO_2; 2.050 mg H_2O. 4.697 mg substance: 6.970 mg CO_2; 2.458 mg H_2O. 0.1068 g substance: 0.0298 g $Mg_2P_2O_7$ (Marie method). 0.1023 g substance: 0.0279 g $Mg_2P_2O_7$. Found %: C 40.35, 40.50; N 5.87, 5.86; P 7.77, 7.43. $C_{14}H_{16}ONa_3PO_4 \cdot 3H_2O$. Calculated %: C 40.18; H 5.26; P 7.4.

When 0.2763 g of the substance was dried to constant weight in a vacuum desiccator, it lost 0.0273 g, equivalent to 10.5% of crystallization water. The formula given above contains 12.9% of water.

The substance colors concentrated sulfuric acid crimson, dilution with water then producing a white precipitate. An aqueous solution of the substance yields a white precipitate with bromine water. It decolorizes a permanganate solution instantaneously.

Methylating the vinylacetylenic phenol (IV) with dimethyl sulfate. 10 grams of the substituted phenol were dissolved in 50 ml of 10% sodium hydroxide, and 12 ml of dimethyl sulfate was added gradually. The mixture was agitated for half an hour; the reaction was accompanied by the evolution of heat. Then sodium hydroxide solution was added until the reaction was alkaline, and the liquid was heated to boiling. After the solution had cooled, the product was extracted with ether, dried with potash, and distilled in vacuo after the ether had been driven off. This yielded 6.5 g of the methyl ester of the substituted phenol (VII) as a colorless, transparent liquid with a b.p. of 123-124° at 4.5 mm.

n_D^{20} 1.5340; d_4^{20} 0.9611; MR_D found 68.9; calculated 67.04.

3.485 mg substance: 10.771 mg CO_2; 2.716 mg H_2O. 3.080 mg substance: 9.503 mg CO_2; 2.405 mg H_2O. 0.1564 g substance; 16.05 g benzene: Δt 0.237°. 0.1242 g substance; 13.63 g benzene: Δt 0.216°. Found %: C 84.34, 84.20; H 8.72, 8.74. M 216.2, 215.3. $C_{15}H_{13}O$. Calculated %: C 84.12; H 8.41. M 214.

Hydrogenation of the vinylacetylenic phenol (IV). 1455 ml of hydrogen was absorbed in 8 hours (the theory calling for 1450 ml) when 405 g of the substance was hydrogenated in 50 ml of ethyl alcohol using an Adams platinum catalyst. The catalyst was then filtered out, the alcohol driven off, and the product distilled in vacuo. This yielded 3.2 g of the hydrogenated product (VI) as a colorless liquid with a b.p. of 131-132° at 4 mm.

n_D^{20} 1.5121; d_4^{20} 0.9551; MR_D found 64.77; calculated 64.69.

5.810 mg substance: 17.327 mg CO_2; 5.538 mg H_2O. 3.070 mg substance: 9.408 mg CO_2; 3.070 mg H_2O. Found %: C 81.4, 81.3; H 10.71, 10.87. $C_{14}H_{22}O$ Calculated %: C 81.55; H 10.73.

Methylation of the furanic phenol (XI). 16 grams of the furanic phenol (XI) (b.p. 156-160° at 3 mm) was dissolved in 100 ml of 10% sodium hydroxide, and 20 ml of dimethyl sulfate was gradually added. The mixture was agitated for half an hour, after which a solution of sodium hydroxide was added until its reaction was alkaline, and the liquid was heated to boiling. When the liquid had cooled, it was extracted with ether, dried with potash, and distilled in vacuo after the ether had been driven off. This yielded 9 g of the methyl ester of the furanic phenol (XII) with a b.p. of 127-127.5 at 2.5 mm.

n_D^{20} 1.5291; d_4^{20} 0.9988; MR_D found 71.8; calculated 68.27.

5.150 mg substance: 14.844 mg CO_2; 4.105 mg H_2O. 6.630 mg substance: 19.087 mg CO_2; 5.185 mg H_2O. 0.2392 g substance; 15.33 g benzene: Δt 0.343°. 0.1405 g substance; 15.33 g benzene: Δt 0.206°. Found %: C 78.64, 78.58; H 8.92, 8.75. M 232, 223.7. $C_{15}H_{20}O_2$. Calculated %: C 77.56; H 8.61; M 232.

Oxidation of the substituted anisole (VII) with permanganate. 38.1 grams of powdered permanganate was gradually added, with stirring and chilling with ice water, to a solution of 10 g of the substituted anisole (VII) in 150 g of acetone (the acetone had first been boiled with potassium permanganate for 8 hours and then distilled). Oxidation took 4 hours. The manganese dioxide was filtered out and thoroughly washed several times with hot water. The filtrates were combined and evaporated to small volume. A few drops of the filtrate threw down a white precipitate of calomel when reacted with mercuric chloride (test for formic acid). After the evaporated filtrate had cooled, it was acidulated with a 1% solution of sulfuric acid, yielding an oily substance that soon crystallized. The crystals were filtered out, washed a few times with cold water, and dried in a desiccator. This yielded 3.6 g of p-methoxyphenyldimethylacetic acid (IX), which had an m.p. of 87-88° after recrystallization from aqueous alcohol.

0.216 g substance: 11.5 ml 0.1 N NaOH. 0.109 g substance: 5.8 ml 0.1 N NaOH.
Found M 188.2, 187.9. Calculated: M 194.

substituted at various positions, with different radicals and with varying degree of addition, and to learn the effect of the nature, quantity, and position of these radicals upon the activity of the double bond and of the carbonyl group in addition reactions. We chose ethylidene acetone, benzalacetone, and furfuralacetone for this investigation, as derivatives of methyl vinyl ketone that contain substituents at the β-carbon atom of the vinyl group.

The procedure employed was the usual one: a saturated alcoholic solution of a sodium alcholate was added drop by drop to a mixture of the dialkylphosphorous acid and the unsaturated ketone. Considerable heat was evolved during the reaction, and the viscosity of the reaction mixture rose substantially. After enough of the alcoholate had been added (the reaction mixture no longer warmed up), the reaction mass was distilled in vacuo. Analysis of the resultant addition products by the Tserevitinov method indicated that they did not contain any hydroxyl group and, hence, were ketophosphinic esters rather than hydroxyphosphinic esters (which could have been formed if the dialkylphosphorous acids had been added at the carbonyl group of the unsaturated ketones).

The dialkylphosphorous acids were added most readily and rapidly to ethylidene acetone. Yields of 62-75% of the addition products, the respective 1-methyl-1-dialkylphosphobutanones-3, were obtained. The constants of the synthesized ketophosphinic esters are listed in Table 1.

TABLE 1

No.	Formula	Boiling point	n_D^{20}	d_4^{20}	Per cent yield
1	$CH_3COCH_2CH(CH_3)P(=O)(OCH_3)_2$	134 - 135° (10 mm)	1.4411	1.1313	69.1
2	$CH_3COCH_2CH(CH_3)P(=O)(OC_2H_5)_2$ . . .	139 - 140 (10 mm)	1.4387	1.0850	62.1
3	$CH_3COCH_2CH(CH_3)P(=O)(OC_4H_9\text{-iso})_2$ . . .	156 - 158 (10 mm)	1.4400	1.0221	63.7
4	$CH_3COCH_2CH(CH_3)P(=O)(OC_4H_9\text{-n})_2$ . . .	172 - 173 (10 mm)	1.4412	0.9985	74.4

Dialkylphosphorous acids are added to benzalacetone more slowly than to ethylidene acetone, though the reaction is just as vigorous, with considerable heat liberated by the reaction mixture. The constants and yields of the synthesized β-ketophosphinic esters, 1-phenyl-1-dialkylphosphobutanones-3, are listed in Table 2.

The dialkylphosphorous acids are added to furfuralacetone at about the same rate as to benzalacetone. The constants of the synthesized β-ketophosphinic esters are listed in Table 3.

In all the investigated reactions involving the addition of dialkylphosphorous acids to unsaturated ketones the addition velocity falls substantially as the molecular weight of the radicals entering into the composition of the dialkylphosphorous acids increases. Hence, the only way to secure more complete and more rapid reactions, especially when dibutyl- and diisobutylphosphorous acids are added, is either to heat the reaction mixture after a given quantity of the saturated alcoholic solution of the alcoholate has been added or to add an excess of the alcholate to the reaction mixture until the exothermal effect ceases. It is likewise of great importance to the producing of pure β-ketophosphinic ethers that the alcoholic solution of a sodium alcoholate employed as a catalyst be prepared from an alcohol containing the same radical as the one entering into the composition of the dialkylphosphorous acid added. The reason for this is that a partial exchange of

radicals occurs during the reaction, as we have discovered, between the molecules of the alcohol and the dialkylphosphorous acid:

$$2CH_3OH + (C_4H_9O)_2POH \xrightarrow{CH_3ONa} 2C_4H_9OH + (CH_3O)_2POH,$$

TABLE 2

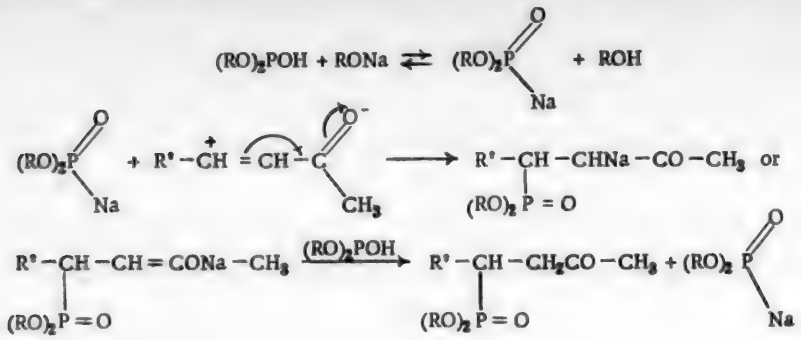
No.	Formula	Boiling point	n_D^{20}	d_4^{20}	Per cent yield
1	$CH_3COCH_2CH(C_6H_5)P(=O)(OCH_3)_2$	189 - 190° (10 mm)	1.5095	1.1791	64.6
2	$CH_3COCH_2CH(C_6H_5)P(=O)(OC_2H_5)_2$	203 (16 mm)	1.5050	1.1309	55.8
3	$CH_3COCH_2CH(C_6H_5)P(=O)(OC_4H_9\text{-iso})_2$	208 (12 mm)	1.4900	1.0736	64.5
4	$CH_3COCH_2CH(C_6H_5)P(=O)(OC_4H_9\text{-n})_2$	219 - 220 (13 mm)	1.4927	1.0737	63.0

TABLE 3

No.	Formula	Boiling point	n_D^{20}	d_4^{20}	Per cent yield
1	$CH_3COCH_2CH(C_4H_9O)P(=O)(OCH_3)_2$	163 - 164° (6 mm)	1.4835	1.2181	44.7
2	$CH_3COCH_2CH(C_4H_9O)P(=O)(OC_2H_5)_2$	192 - 193 (16 mm)	1.4755	1.1616	62.0
3	$CH_3COCH_2CH(C_4H_9O)P(=O)(OC_4H_9\text{-iso})_2$	161 (3 mm)	1.4711	1.0932	72.1
4	$CH_3COCH_2CH(C_4H_9O)P(=O)(OC_4H_9\text{-n})_2$	182 (4 mm)	1.4730	1.0995	60.0

resulting in the formation of a dialkylphosphorous acid with a different radical and in contaminating the principal reaction product due to the addition of this new acid to the unsaturated ketone.

The general pattern for the addition of dialkylphosporous acids to unsaturated ketones that contain one substituted group attached to the β-carbon atom of the vinyl group may be represented as follows:



The acids produced by saponifying the synthesized ketophosphinic esters are thick, oily liquids that do not crystallize upon standing.

EXPERIMENTAL

Addition of Dialkylphosphorous Acids to Ethylideneacetone

1. Addition of dimethylphosphorous acid. A saturated solution of sodium methylate in methanol was added slowly, drop by drop, to a mixture of 8.4 g of ethylidene acetone and 11 g of dimethylphosphorous acid. The reaction mixture heated up considerably; the addition of the sodium methylate was regulated so as to keep the temperature of the reaction mixture from going higher than 60-70°. The sodium methylate was added until no more heat was evolved by the reaction mixture. The viscosity of the reaction mixture rose appreciably during the course of the reaction. Fractionation of the mixture from an Arbuzov flask yielded 13.4 g of 1-methyl-1-dimethylphosphobutanone-3 with a b.p. of 134-135° at 10 mm.

0.1326 g, 0.1300 g substance: 32.1 ml, 31.0 ml NaOH (T = 0.024417).
Found %: P 15.8, 16.1. $C_7H_{15}O_4P$. Calculated %: P 15.9.

2. Addition of diethylphosphorous acid. A saturated solution of sodium ethylate in ethyl alcohol was added a drop at a time to a mixture of 8.4 g of ethylidene acetone and 14 g of diethylphosphorous acid. After the reaction was complete, fractionation of the reaction mixture yielded 13.9 g of 1-methyl-1-diethylphosphobutanone-3 with a b.p. of 139-140° at 10 mm.

0.1302 g, 0.0978 g substance: 26.5 ml 20.4 ml NaOH (T = 0.024417).
Found %: P 13.8, 14.1. $C_7H_{19}O_4P$. Calculated %: P 14.0.

3. Addition of diisobutylphosphorous acid. A solution of sodium isobutylate in isobutyl alcohol was added to a mixture of 8.4 g of ethylidene acetone and 18.6 g of diisobutylphosphorous acid. Much less heat was evolved than in the preceding reactions. The amount of the saturated solution of sodium isobutylate that was added totaled some 2 ml. Fractionation of the reaction mixture yielded 17.2 g of 1-methyl-1-diisobutylphosphobutanone-3 with a b.p. of 156-158° at 10 mm.

0.1186 g substance: 20.0 ml NaOH (T = 0.024417).
Found %: P 11.6. $C_{13}H_{27}O_4P$. Calculated %: P 11.2.

4. Addition of dibutylphosphorous acid. The amounts of reagents employed in this reaction were the same as in the preceding one, sodium butylate being used, however. The yield was 20.1 g of 1-methyl-1-dibutylphosphobutanone-3 with a b.p. of 172-173° at 10 mm.

0.1248 g substance: 20.7 ml NaOH (T = 0.024417).
Found %: P 11.20 $C_{13}H_{27}O_4P$. Calculated %: P 11.20.

Addition of Dialkylphosphorous Acids to Benzalacetone

The experimental procedure employed resembled that described in the preceding experiments.

1. Addition of dimethylphosphorous acid. 10 g of benzalacetone and 7.5 g of dimethylphosphorous acid in the presence of sodium methylate yielded 11.3 g of 1-phenyl-1-dimethylphosphobutanone-3 with a b.p. of 189-190° at 10 mm.

0.1792 g substance: 39.8 ml NaOH (T = 0.019404). Found %: P 11.9. $C_{12}H_{17}O_4P$. Calc.%: P 12.1.

2. Addition of diethylphosphorous acid. A saturated solution of sodium ethylate in ethyl alcohol was added to a mixture consisting of 12 g of benzalacetone and 12 g of diethylphosphorous acid. Fractionation of the reaction mixture yielded 13.4 g of 1-phenyl-1-diethylphosphobutanone-3 with a b.p. of 203° at 16 mm.

0.1336 g, 0.1316 g substance: 26.7 ml, 26.7 ml NaOH (T = 0.019404). Found %: P 10.8, 10.9. $C_{14}H_{21}O_4P$. Calculated %: P 10.9.

3. Addition of diisobutylphosphorous acid. 7.3 g of benzalacetone and 10 g of diisobutylphosphorous acid in the presence of sodium isobutylate yielded 11.2 g of 1-phenyl-1-diisobutylphosphobutanone-3 with a b.p. of 208° at 12 mm.

0.1426 g, 0.1188 g substance: 25.2 ml, 20.5 ml NaOH (T = 0.019404). Found %: P 9.4, 9.2. $C_{18}H_{29}O_4P$. Calculated %: P 9.1.

4. Addition of dibutylphosphorous acid. 10.8 g of benzalacetone and 15 g of dibutylphosphorous acid yielded 16.2 g of 1-phenyl-1-dibutylphosphobutanone-3 with a b.p. of 219-220° at 13 mm.

0.1340 g substance: 24.4 ml NaOH (T = 0.019404) Found %: P 9.6. $C_{18}H_{29}O_4P$. Calculated %: P 9.1.

Addition of Dialkylphosphorous Acids to Furfuralacetone

1. Addition of dimethylphosphorous acid. 10 g of furfuralacetone and 9 g of dimethylphosphorous acid in the presence of sodium methylate yielded 8.5 g of 1-furyl-1-dimethylphosphobutanone-3 with a b.p. of 163-164° at 6 mm.

0.1178 g substance: 28.1 ml NaOH (T = 0.019404). Found %: P 12.8. $C_{10}H_{15}O_5P$. Calculated %: P 12.6.

2. Addition of diethylphosphorous acid. 10 g of furfuralacetone and 10 g of diethylphosphorous acid in the presence of sodium ethylate yielded 12.4 g of 1-furyl-1-diethylphosphobutanone-3 with a b.p. of 192-193° at 16 mm.

0.1630 g, 0.1270 g substance: 34.5 ml, 27.0 ml NaOH (T = 0.019404). Found %: P 11.4, 11.3. $C_{12}H_{19}O_5P$. Calculated %: P 11.3.

3. Addition of diisobutylphosphorous acid. 13.7 g of furfuralacetone and 21.0 g of diisobutylphosphorous acid yielded 25 g of 1-furyl-diisobutylphosphobutanone-3 with a b.p. of 161° at 3 mm.

0.1110 g substance: 19.6 ml NaOH (T = 0.019404). Found %: P 9.5. $C_{16}H_{27}O_5P$. Calc.%: P 9.4.

4. Addition of dibutylphosphorous acid. 7 g of furfuralacetone and 11 g of dibutylphosphorous acid in the presence of sodium butylate yielded 10.8 g 1-furyl-1-dibutylphosphobutanone-3 with a b.p. of 182° at 4 mm.

0.1104 g, 0.1214 g substance: 20.0 ml, 21.8 ml NaOH (T = 0.019404). Found %: P 9.7, 9.3. $C_{16}H_{27}O_5P$. Calculated %: P 9.4.

SUMMARY

1. A new method has been developed for synthesizing β-ketophosphinic esters by adding dialkylphosphorous acids to α, β-unsaturated ketones in the presence of alcoholates of alkali metals.

2. The addition products of dimethyl-, diethyl-, diisobutyl-, and dibutyl-phosphorous acids to ethylidene acetone, benzalacetone, and furfuralacetone have been isolated and identified.

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THE ADDITION OF DIALKYLPHOSPHOROUS ACIDS TO UNSATURATED COMPOUNDS

IV. THE ADDITION OF DIALKYLPHOSPHOROUS ACIDS TO UNSATURATED ALDEHYDES

A NEW METHOD OF SYNTHESIZING UNSATURATED α-HYDROXYPHOSPHINIC ESTERS

A. N. Pudovik and Yu. P. Kitaev

In our previous report [1] we described the addition of dialkylphosphorous acids to some electronophilic reagents belonging to the group of unsaturated nitriles, acid esters, and ketones. We showed that when catalysts—alcoholates of the alkali metals—are present, addition takes place very readily at the double bond, resulting in the formation of derivatives of phosphinic esters. This discovery of a new method of synthesizing phosphinic esters made cyanophosphinic, carboxylalkylphosphinic, and ketophosphinic esters of diversified structure highly accessible, though their preparation by the other methods known at the present time sometimes involved substantial preparative difficulties.

In the present research we decided to employ our newly discovered reaction of the addition of dialkylphosphorous acids to unsaturated electronophilic reagents to α,β-unsaturated aldehydes, using it to synthesize hitherto unknown esters of aldehydophosphinic acids. The substances we proposed to employ were acrolein, crotonaldehyde, furylacroline, cinnamaldehyde, and hexadienal.

We introduced some changes into the reaction procedure described in our preceding papers to increase the yield of the addition products. A saturated *alcoholic* solution of a sodium alcoholate was added dropwise to a mixture of equimolecular quantities of the unsaturated *aldehyde* and the dialkylphosphorous acid. Considerable heat was evolved during the reaction, the addition of the alcoholate being stopped as soon as the evolution of heat by the reaction mixture ceased. To avoid losses, the addition reaction was performed directly in an Arbuzov flask in the presence of a small amount of hydroquinone, which protected the unsaturated aldehyde against polymerization during the course of the reaction and during fractionation. With the same objective in view, the sodium alcoholate present in the reaction mixture was neutralized by the addition of a few drops of glacial acetic acid before fractionation was begun. When the end products were solids that were soluble with difficulty in organic solvents, the reactions were carried out in an alcohol solution; the addition products settled out of the solution as crystalline precipitates and were then recrystallized from a water-alcohol mixture.

Of all the unsaturated aldehydes used, dialkylphosphorous acids are added most readily and rapidly to acrolein. Much less catalyst was required to complete the reaction when dimethyl- and diethylphosphorous acids were added than in the addition of the higher dialkylphosphorous acids. As we have stated in our preceding paper [2], the purest products are obtained when the alcoholates, the alcohols, and the dialkylphosphorous acids all contained the same radicals.

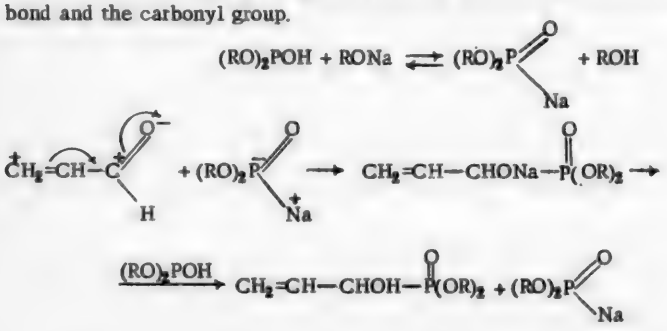
A study of some of the products of the addition of dialkylphosphorous acids to acrolein has shown that they display no characteristic reactions for a carbonyl group, more specifically failing to react with hydroxylamine, phenylhydrazine, p-dinitrophenylhydrazine, and semicarbazide. Titration with bromine indicated that they possessed a double bond, while a Tserevitinov analysis established the presence of a hydroxyl group. Our findings led us to conclude that the addition products were not aldehydo-phosphinic esters, as we had presupposed, but unsaturated hydroxyphosphinic esters, so that dialkylphosphorous acids are not added to unsaturated aldehydes at the double bond, but at the carbonyl group.

The constants and yields of the synthesized unsaturated α-hydroxyphosphinic esters are listed in Table 1.

TABLE 1

Compound No.	Formula	B.p.	n_D^{20}	d_4^{20}	MR_D Found	MR_D Calculated	% Yield
1	$CH_2=CH-CH(OH)P(=O)(OCH_3)_2$	149–151° (13 mm)	1.4572	1.2188	37.1	37.2	66.2
2	$CH_2=CH-CH(OH)P(=O)(OC_2H_5)_2$	154–155 (13 mm)	1.4506	1.1225	46.5	46.5	77.1
3	$CH_2=CH-CH(OH)P(=O)(OC_3H_7\text{-iso})_2$	140–141 (7 mm)	1.4415	1.0465	56.1	55.7	69.8
4	$CH_2=CH-CH(OH)P(=O)(OC_4H_9\text{-iso})_2$	168–170 (13 mm)	1.4348	0.9968	65.4	64.9	14.0
5	$CH_2=CH-CH(OH)P(=O)(OC_4H_9\text{-n})_2$	169–172 (13 mm)	1.4411	1.0130	65.2	64.9	15.0

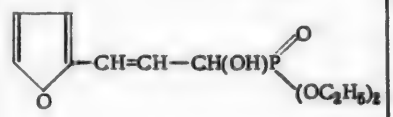
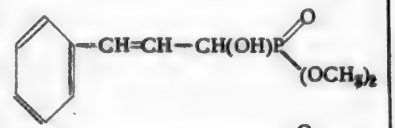
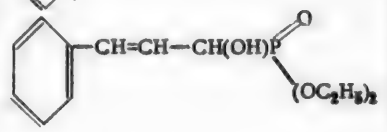
The esters are colorless, mobile liquids with a peculiar fish-oil odor. They are freely soluble in organic solvents. Their formation may be represented as follows: (See below). In their addition to acrolein, therefore, the dialkylphosphorous acids behave very much like many other reagents, such as hydrogen cyanide and sodium bisulfite, which are also added at the carbonyl group for the most part. The contrast in the behavior of structurally similar aldehydes and ketones in addition reactions may be attributed to the fact that in the latter the electronophilic nature of the carbon atom in the carbonyl group is greatly reduced, owing to the steric and electronic (±I effect) influence of the substituent R group, so that the double bond proves to be more active during addition. From this standpoint considerable interest is attached to a study of the addition reactions of dialkylphosphorous acids to unsaturated ketones possessing two substituents attached to the β-carbon atom of the vinyl group, say, to mesityl oxide and others, in which the electronophilic nature of the end carbon atom ought to be greatly reduced and, hence, addition ought to take place at both the double bond and the carbonyl group.



It is extremely interesting that the addition of dialkylphosphorous acids to crotonaldehyde is much less smooth than to acrolein. The yields of the addition products of dimethyl- and diethylphosphorous acids to crotonaldehyde turned out to be very low, while no addition products could be recovered at all in the case of the dibutyl- and diisobutylphosphorous acids. The addition of dimethylphosphorous acid to furylacrolein and cinnamaldehyde produces yields that are nearly quantitative, the addition products being crystalline substances that were freely soluble in organic solvents but only slightly soluble in cold water. Tserevitinov

analysis of these products indicated that they contained a hydroxyl group and, hence, also unsaturated hydroxyphosphinic esters. The constants of the addition products of the dialkylphosphorous acids to crotonaldehyde, furylacrolein, and cinnamaldehyde are given in Table 2.

TABLE 2

Compound No.	Formula	B.p.	M.p.	n_D^{20}	d_4^{20}	% Yield
1		150-152° (8 mm)	–	1.4630	1.1690	–
2		163-164 (9 mm)	–	1.4555	1.1005	–
3		–	106-107°	–	–	87.2
4		–	101-102	–	–	87.0
5		–	104-105	–	–	75.4

Finally, we investigated the addition of dimethylphosphorous and diethylphosphorous acids to hexadien-2,4-al-1. The reaction is fairly vigorous, considerable heat being evolved. Processing and fractionation of the reaction mixtures produced small yields of the following addition products: 1-dimethylphosphohexadien-4-2,4-ol-1, with a b.p. of 153-154° (13 mm); n_D^{20} 1.4866, d_4^{20} 1.1165, and 1-diethylphosphohexadien-2,4-ol-1, with a b.p. of 167-168° (17 mm); n_D^{20} 1.4774, d_4^{20} 1.0717.

The diene hydroxyphosphinic esters are faintly yellow liquids with a peculiar odor, which are readily soluble in alcohol and in ether.

EXPERIMENTAL

I. Addition of Dialkylphosphorous Acids to Acrolein.

1. Addition of dimethylphosphorous acid. A small quantity (about 15 drops) of a saturated solution of sodium methylate was added drop by drop to a reaction mixture consisting of 7.5 g of acrolein stabilized with hydroquinone and 15 g of dimethylphosphorous acid in a small Arbuzov flask, the flask being cooled with water. The reaction was violent, the reaction mixture becoming very hot. After the sodium methylate had been neutralized by adding acetic acid, the reaction mixture was fractionated in vacuo, yielding 12 g of the methyl ester of 1-hydroxy-2-propene-1-phosphinic acid (Table 1, Compound 1).

0.1394 g substance: 52.5 ml NaOH (T = 0.01768). Found %: P 18.45. $C_5H_{11}O_4P$. Calc.%: P 18.68.

The 1-hydroxy-2-propene-1-phosphinic acid, secured by saponifying the ester with dilute hydrochloric acid, was a thick, oily, light-brown liquid that did not crystallize upon standing.

2. Addition of diethylphosphorous acid. About 40 drops of a saturated alcoholic solution of sodium ethylate was added to a mixture consisting of 7 g of acrolein and 22.3 g of diethylphosphorous acid. Fractionation of the reaction mixture yielded 19 g of the ethyl ester of 1-hydroxy-2-propene-1-phosphinic acid. (Table 1, Compound 2).

0.1060 g substance: 43.40 ml NaOH (T = 0.01768). Found %: P 16.34. $C_7H_{15}O_4P$. Calc.%: P 15.98.

3. Addition of diisopropylphosphorous acid. 2.5 g of acrolein and 5.4 g of diisopropylphosphorous acid, under conditions similar to those described for the preceding experiments, yielded 5.3 g of the diisopropyl ester of 1-hydroxy-2-propene-1-phosphinic acid (Table 1, Compound 3).

0.1002 g substance: 27.9 ml NaOH (T = 0.01768). 0.1103 g substance: 13.05 ml CH_4.
Found %: P 13.66; OH 7.91. $C_9H_{19}O_4P$. Calculated %: P 13.96; OH 7.65.

4. Addition of diisobutylphosphorous acid. 5.3 g of acrolein and 15.7 g of diisobutylphosphorous acid yielded 4.5 g of the diisobutyl ester of 1-hydroxy-2-propene-1-phosphinic acid (Table 1, Compound 4), plus several low-boiling fractions.

0.2132 g substance: 54.5 ml NaOH (T = 0.01768). Found %: P 12.52. $C_{11}H_{23}O_4P$. Calculated %: P 12.40.

5. Addition of dibutylphosphorous acid. 10.2 g of acrolein and 32 g of dibutylphosphorous acid were used for the reaction. Repeated fractionation of the reaction mixture yielded 3.7 g of the dibutyl ester of 1-hydroxy-2-propene-1-phosphinic acid (Table 1, Compound 5), plus several low-boiling fractions. The fractionation residue totaled 20 g.

0.2093 g substance: 54.1 ml NaOH (T = 0.01768). Found %: P 12.65. $C_{11}H_{23}O_4P$. Calculated %: P 12.40.

II. Exchange of Radicals Between the Alcohols and The Dialkylphosphorous Acids in the Presence of Alcoholates of the Alkali Metals.

Experiment 1. 10.8 g of dimethylphosphorous acid, 14.1 g of butyl alcohol, and 0.75 g of a saturated solution of sodium methylate were placed in an Arbuzov flask. The reaction mixture was distilled after having been allowed to stand for twenty minutes at room temperature. This yielded 5.5 g of methanol, 5.9 g of butyl alcohol, 3.8 g of dimethylphosphorous acid, and 4.9 g of dibutylphosphorous acid.

Experiment 2. A similar reaction was carried out with 9.6 g of dibutylphosphorous acid, 4 g of methanol, and 0.35 g of a saturated solution of sodium methylate. This yielded 1.5 g of butyl alcohol, 0.5 g of dimethylphosphorous acid, and 6.1 g of dibutylphosphorous acid.

III. Addition of Dialkylphosphorous Acids to Crotonaldehyde.

1. Addition of dimethylphosphorous acid. Some 60 drops of an alcoholic solution of sodium methylate was gradually added from a dropping funnel to a chilled mixture of 5 g of crotonaldehyde and 11.6 g of dimethylphosphorous acid. Repeated fractionation of the reaction products yielded 0.85 g of the methyl ester of 1-hydroxy-2-butene-1-phosphinic acid (Table 2, Compound 1), plus several low-boiling fractions. The fractionation residue totaled 8.9 g.

0.1604 g substance: 57.18 ml NaOH (T = 0.01768). Found %: P 17.45. $C_6H_{13}O_4P$. Found %: P 17.23.

2. Addition of diethylphosphorous acid. 5.1 g of crotonaldehyde and 12.9 g of diethylphosphorous acid yielded 1.5 g of the diethyl ester of 1-hydroxy-2-butene-1-phosphinic acid (Table 2, Compound 2), plus several low-boiling fractions.

0.2061 g substance: 60.24 ml NaOH (T = 0.01768). Found %: P 14.64 $C_8H_{17}O_4P$. Calculated %: P 14.90.

Saponification of the ester by heating it with dilute hydrochloric acid yielded 1-hydroxy-2-butene-1-phosphinic acid as a thick, oily liquid that did not crystallize upon standing.

IV. Addition of Diethylphosphorous Acid to Furylacrolein.

6.5 g of furylacrolein (m.p. 52.5°) and 7.8 g of diethylphosphorous acid were dissolved in 24 ml of absolute ethyl alcohol. The color of the solution turned from yellow to cherry-red when 10 drops of a saturated alcoholic solution of sodium ethylate was added. Considerable heat was evolved by the reaction mixture. After some more sodium ethylate (20 drops) had been added and the reaction mixture had been heated on a water bath for an hour, a crystalline precipitate began to settle out. Chilling the flask caused 8.6 g of a crystalline precipitate as white leaflets to settle out. Evaporation of the mother liquor yielded another 3 g of the crystalline product. The m.p. of the product was 106-107° after it had been dried in a vacuum desiccator.

0.1681 g substance: 40.17 ml NaOH (T = 0.01768). Found %: P 11.99. $C_{11}H_{17}O_5P$. Calculated %: P 11.92.

We were unable to secure any crystalline addition products in similar reactions of furylacrolein with dimethylphosphorous and dibutylphosphorous acid. The addition products were thick oily liquids that did not crystallize upon standing and did not distil in vacuo.

V. Addition of Dialkylphosphorous Acids to Cinnamaldehyde.

1. Addition of dimethylphosphorous acid. A saturated solution of sodium methylate in methanol was added drop by drop to a reaction mixture consisting of 4.6 g of cinnamic aldehyde and 4 g of dimethylphosphorous acid. The mixture heated up considerably (to +75°) and grew much more viscous. The contents of the flask crystallized into a solid yellow mass after standing for one hour at room temperature. Recrystallization from an aqueous-alcoholic solution and drying in a vacuum desiccator yielded 7 g of the dimethyl ester of 1-hydroxy-3-phenyl-2-propene-1-phosphinic acid as minute colorless crystals. The crystals were freely soluble in alcohol, ether, benzene, and chloroform, less so in gasoline, and sparingly soluble in water.

0.2024 g substance: 53.2 ml NaOH (T = 0.01768). 0.0853 g substance: 8.9 ml CH_4.
Found %: P 12.86; OH 7.28. $C_{11}H_{15}O_4P$. Calculated %: P 12.81; OH 7.02.

Saponification of the dimethyl ester of 1-hydroxy-3-phenyl-2-propene-1-phosphinic acid. 2.4 g of the ester was heated to 100° in a sealed tube for 19 hours with 30 ml of dilute hydrochloric acid. After the methyl chloride had been driven off and the aqueous solution had been boiled with activated charcoal, the solution was evaporated to a thick, tacky mass. No acid crystallized out despite the long time the mass was allowed to stand. A barium salt of the acid was secured by boiling it with barium carbonate. The salt crystallized from the concentrated solution as tiny white platelets. They were dried at 110-120° and analyzed for their barium content.

0.1439 g substance: 0.0598 g $BaSO_4$. Found %: Ba 24.44. $C_{18}H_{20}O_8P_2Ba$ Calculated %: Ba 24.37.

2. Addition of diethylphosphorous acid. 4.07 g of diethylphosphorous acid and 4.05 g of cinnamic aldehyde were used for the reaction, which was carried out as in the addition of the dimethylphosphorous acid. The reaction yielded a crystalline product that had a m.p. of 104-105° after having been recrystallized from a water-alcohol solution. The product totaled 6 g of minute, fairly yellow needles with the odor of cinnamon, soluble in alcohol, ether, benzene, and chloroform, and slightly soluble in water.

0.1949 g substance: 42.1 ml NaOH (T = 0.01768). Found %: P 11.58. $C_{13}H_{19}O_4P$. Calculated %: P 11.48.

The addition of dibutylphosphorous and diisobutylphosphorous acids to cinnamaldehyde yielded thick, oily products that did not crystallize upon standing and could not be distilled in vacuo without decomposing.

VI. Addition of Dialkylphosphorous Acids to Hexadien-2,4-al-1.

1. Addition of dimethylphosphorous acid. 5.1 g of hexadien-2,4-al-1 and 6 g of dimethylphosphorous acid were placed in a small Arbuzov flask. As the sodium methylate was added drop by drop, the reaction mixture grew very hot. Double fractionation yielded about 2 g of the addition product — 1-dimethylphosphohexadien-2,4-ol-1 with a b.p. of 153-154° (13 mm); n_D^{20} 1.4866, d_4^{20} 1.1165.

0.1676 g substance: 50.3 ml NaOH (T = 0.01786). Found %: P 14.69. $C_8H_{15}O_4P$. Calculated %: P 15.02.

2. Addition of diethylphosphorous acid. The reaction of 7.5 g of diethylphosphorous acid with 5.2 g of the hexadienal yielded 1.4 g of 1-diethylphosphohexadien-2,4-ol-1 with a b.p. of 167-168° (17 mm); n_D^{20} 1.4774, d_4^{20} 1.0717.

0.1020 g substance: 28.5 ml NaOH (T = 0.01768). Found %: P 13.70. $C_{10}H_{19}O_4P$. Calculated %: P 13.22.

1-Diethylphosphohexadien-2,4-ol-1 is a thick, yellow liquid with a peculiar odor that is freely soluble in alcohol and ether.

SUMMARY

1. It has been shown that dialkylphosphorous acids are added to α,β-unsaturated aldehydes at the carbonyl group in the presence of alcoholates of the alkali metals, giving rise to esters of unsaturated α-hydroxyphosphinic acids.

2. The addition products of dialkylphosphorous acids to acrolein, cinnamaldehyde, crotonaldehyde, furylacrolein, and hexadien-2,4-al-1 have been prepared and identified.

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THE ADDITION OF DIALKYLPHOSPHOROUS ACIDS TO UNSATURATED COMPOUNDS

V. THE ADDITION OF DIALKYLPHOSPHOROUS ACIDS TO METHYL ACRYLATE, VINYL ACETATE, and VINYL BUTYL ETHER

A. N. Pudovik

As we have shown in a series of papers, the addition of dialkylphosphorous acids to unsaturated electronophilic reagents discovered by us may be employed as a simple and convenient method of synthesizing various ketophosphinic [1,3], cyanophosphinic [2], and carboxyalkylphosphinic esters, and unsaturated α-hydroxyphosphinic ethers [4]. The reaction takes place very readily in the presence of alcoholates of the alkali metals, the yields of the addition products being fairly high. Of the esters of α,β unsaturated carboxylic acids, the only one we have used for these reactions is methyl methacrylate. In the present paper we have made a study of the addition of dialkylphosphorous acids to methyl acrylate, vinyl butyl ether, and vinyl acetate by way of a more comprehensive and thoroughgoing study of the addition of dialkylphosphorous acids to esters of unsaturated carboxylic acids and to ethers of unsaturated alcohols, and to learn the effect of the structure of reagents upon their ability to enter into addition reactions.

In connection with these presuppositions, it was found that the addition of dialkylphosphorous acids to methyl acrylate, which contains an unsubstituted vinyl group, is much more energetic than that to methyl methacrylate. The addition reactions were carried out by a procedure similar to that described in our preceding papers [1-4]. The addition of dimethylphosphorous, diethylphosphorous, diisobutylphosphorous, and dibutylphosphorous acids to methyl acrylate yielded the corresponding addition products, the methyl esters of β-dialkylphosphopropionic acid, whose constants, molecular refraction, and yields are listed in Table 1.

TABLE 1

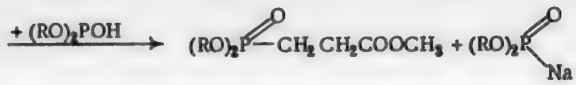
No.	Formula	Boiling point (°C)	n_D^{20}	d_4^{20}	MR_D Found	MR_D Calculated	Yield, %
1	$(CH_3O)_2P(=O)-CH_2CH_2COOCH_3$	137-138° (10 mm)	1.4390	1.2170	42.36	42.43	73
2	$(C_2H_5O)_2P(=O)-CH_2CH_2COOCH_3$	154-155 (14 mm)	1.4346	1.1241	51.97	51.66	84
3	$(iso\text{-}C_4H_9O)_2P(=O)-CH_2CH_2COOCH_3$	172-174 (12 mm)	1.4400	1.0495	70.31	70.13	77
4	$(n\text{-}C_4H_9O)_2P(=O)-CH_2CH_2COOCH_3$	183-186 (11 mm)	1.4416	1.0480	70.63	70.13	76

Saponifying the methyl ester of β-diethylphosphopropionic acid yielded β-phosphopropionic acid as minute crystals; their m.p. was 172-173° after having been dried in air. Nylen [5] gives the m.p. of β-phosphopropionic acid as 178°; α-phosphopropionic acid melts at 119-132° and deliquesces when left to stand in the air, according to Nylen [6] and A.E.Arbuzov and A.I. Razumov [7]. These findings on the saponification of the resultant addition products corroborate the formulas proposed for their structure as methyl esters of β-dialkylphosphopropionic acids.

The addition reactions may be pictured as follows:

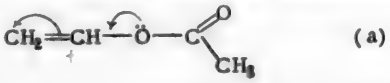
$$(RO)_2POH + RONa \rightleftharpoons (RO)_2P(=O)Na + ROH$$

$$(RO)_2P(=O)Na + CH_2=CH-C(=O)OCH_3 \longrightarrow (RO)_2P(=O)-CH_2-CHNaCOOCH_3, \text{ or } (RO)_2P(=O)-CH_2-CH=C(ONa)OCH_3 \longrightarrow$$



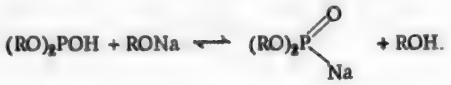
We then made a study of the addition of dialkylphosphorous acids to vinyl butyl ether and vinyl acetate. Vinyl butyl ether is a typical nucleophilic reagent, and as we have established, dialkylphosphorous acids are not added to this ether in the presence of alcoholates of the alkali metals. Nor were we able to effect this addition in the presence of protons (phosphoric acid), though carboxylic acids are added with great ease to vinyl ethers under analogous conditions, [8].

It might have been thought that vinyl acetate would be much more nucleophilic



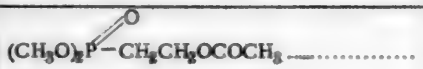
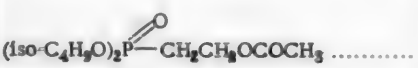
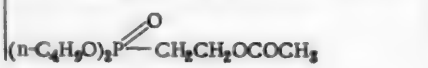
(a)

than electronophilic (a) and thus would be just as inert toward the addition of dialkylphosphorous acids. It was found, however, that the electronophilic nature of vinyl acetate is rather pronounced, as dialkylphosphorous acids are added to it quite energetically in the presence of alcoholates of the alkali metals. The addition obviously occurs directly at the carbon-carbon double bond and may be represented as follows:



The constants, the molecular refraction values, and the yields of the resultant addition products – β-dialkylphosphoethyl acetates – are listed in Table 2.

TABLE 2

No.	Formula	Boiling point	n_D^{20}	d_4^{20}	MRD		Yield, %
					Found	Calculated	
1		104-105° (5 mm)	1.4298	1.1882	42.59	42.43	72
2		124-125° (9 mm)	1.4266	1.0214	51.33	51.66	57
3		147 (10 mm)	1.4325	1.0263	70.83	70.13	56
4		143 (6 mm)	1.4312	1.0275	70.54	70.13	33

Saponification of β-diethylphosphoethyl acetate yielded β-hydroxyethylphosphinic acid as a viscous, straw-yellow oil. The acid did not crystallize even after long standing.

EXPERIMENTAL

Addition of dimethylphosphorous acid to methyl acrylate. A saturated solution of sodium methylate in methanol was slowly added, drop by drop, to a reaction mixture consisting of 11 g of dimethylphosphorous acid and 8.6 g of methyl acrylate, placed in a small Arbuzov flask. The reaction was extremely violent, with loud crackling and foaming of the reaction mixture. The reaction flask was cooled with cold water during the reaction. The sodium methylate solution was added a drop at a time until the reaction mass no longer grew warm, a total of some 20-25 drops of the methylate being added. Fractionation of the reaction mixture yielded 14.3 g of the methyl ester of β-dimethylphosphopropionic acid (Table 1, Compound 1).

0.1416 g substance: 0.0908 g substance: 39.5 ml, 26.9 ml NaOH (T = 0.019589).
Found %: P 15.8, 16.0. $C_6H_{13}O_5P$. Calculated %: P 15.7.

Addition of diethylphosphorous acid to methyl acrylate. 16 grams of diethylphosphorous acid and 10 g of methyl acrylate were used in the reaction in the presence of sodium ethylate, the procedure being the same as that described in the preceding experiment. Fractionation of the reaction mixture yielded 21.8 g of the methyl ester of β-diethyl-phosphopropionic acid (Table 1, Compound 2).

0.1240 g substance, 0.1342 g substance: 30.8 ml, 33.5 ml NaOH (T = 0.019589). Found %: P 13.5, 13.6. $C_8H_{17}O_5P$. Calculated %: P 13.8.

Saponification of the methyl ester of β-diethylphosphopropionic acid. 3.8 g of the ester was heated to 130-140° for 8 hours with 40 ml of 1:1 dilute hydrochloric acid. This yielded 2.2 g of ethyl chloride (2.1 g being called for theoretically). The hydrochloric acid was eliminated by repeated evaporation of the reaction mixture, with distilled water added after each evaporation. When the reaction mixture was evaporated to small volume, white crystals settled out, which had a m.p. of 172-173° after double recrystallization from water and drying in air.

0.1368 g substance: 50.3 ml NaOH (T = 0.019589). Found %: P 20.0. $C_3H_7O_3P$. Calc. %: P 20.1.

Addition of diisobutylphosphorous acid to methyl acrylate. The reaction was carried out with 14.6 g of diisobutylphosphorous acid and 6 g of methyl acrylate in the presence of sodium diisobutylate. The yield was 15.8 g of the methyl ester of β-diisobutylphosphopropionic acid (Table 1, Compound 3).

0.1022 g substance: 21.3 ml NaOH (T = 0.019589). Found %: P 11.3. $C_{12}H_{25}O_5P$. Calc.%: P 11.1.

Addition of dibutylphosphorous acid to methyl acrylate. A saturated solution of sodium butylate in butyl alcohol was added a drop at a time to a mixture of 8.3 g of dibutylphosphorous acid and 4 g of methyl acrylate. The reaction involved the evolution of considerable heat. A total of approximately 1 ml of the butylate solution was added. Fractionation of the reaction mixture yielded 9.4 g of the methyl ester of β-dibutylphosphopropionic acid (Table 1, Compound 4).

0.0944 g substance: 19.6 ml NaOH (T = 0.019589). Found %: P 11.4. $C_{12}H_{25}O_5P$. Calc.%: P 11.1.

Addition of dialkylphosphorous acids to vinyl acetate. 1. Addition of dimethylphosphorous acid. A saturated solution of sodium methylate in methanol was added very slowly, a drop at a time, to a reaction mixture consisting of 8.6 g of vinyl acetate and 11 g of dimethylphosphorous acid placed in an Arbuzov flask. The reaction caused the reaction mixture to warm up considerably; characteristic crackling was audible when the first few drops of the methylate were added. The sodium methylate was added until the reaction mixture did not heat up any longer, a total of about 20 drops being added in the course of 30 minutes. Fractionation of the reaction mixture yielded 14.1 g of β-dimethylphosphoethyl acetate (Table 2, Compound 1).

0.1312 g substance, 0.1284 g substance: 38.6 ml NaOH, 38.1 ml NaOH (T = 0.019589). Found %: P 16.0, 16.1. $C_6H_{13}O_5P$. Calculated %: P 15.7.

2. Addition of diethylphosphorous acid. 9 g of vinyl acetate and 13.1 g of diethylphosphorous acid were used for the reaction in the presence of sodium ethylate, which was carried out as specified above. Fractionation of the reaction mixture yielded 12.5 g of β-diethylphosphoethyl acetate (Table 2, Compound 2).

0.1160 g substance: 29.5 ml NaOH (T = 0.019589). Found %: P 13.8. $C_8H_{17}O_5P$. Calc.%: P 13.8.

3. Addition of diisobutylphosphorous acid. 4.3 g of vinyl acetate and 9.3 g of diisobutylphosphorous acid were used in this reaction, which was carried out in the presence of sodium isobutylate. The reaction was much quieter, with less heat evolved, than in the first two experiments. Fractionation of the reaction mixture yielded 7.6 g of β-diisobutylphosphoethyl acetate (Table 2, Compound 3).

0.1320 g substance: 27 ml NaOH (T = 0.019589). Found %: P 11.1. $C_{12}H_{25}O_5P$. Calc.%: P 11.1.

4. Addition of dibutylphosphorous acid. The reaction was carried out with 15 g of vinyl acetate and 11 g of dibutylphosphorous acid in the presence of sodium butylate. The yield was 9.5 g of β-dibutylphosphoethyl acetate (Table 2, Compound 4).

0.0944 g substance: 19.6 ml NaOH (T = 0.019589). Found %: P 11.4. $C_{12}H_{25}O_5P$. Calc.%: P 11.1.

SUMMARY

1. It has been shown that the dialkylphosphorous acids are added to methyl acrylate and vinyl acetate in the presence of alcoholates of the alkali metals, giving rise to the corresponding methyl esters of α,β-dialkylphosphopropionic acid and to β-dialkylphosphoethyl acetates.

2. The dialkylphosphorous acids are not added to vinyl butyl ether in the presence of alcoholates of the alkali metals or of phosphoric acid.

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PHOTOREACTIONS OF ORGANOMETALLIC COMPOUNDS OF MERCURY IN SOLUTIONS

IX. THE REACTIONS OF p-DIANISYLMERCURY

Yu. A. Oldekop and N. N. Zolotareva

In our previous reports [1] we investigated the photoreactions of diphenyl-, dibenzyl-, o-ditolyl-, p-ditolyl-, α-dinaphthyl-, and dimesitylmercury in various organic solvents, finding certain general patterns of the behavior of the various radicals in photoreactions occurring in organic solvents. The organomercury compounds tested contained radicals of aromatic hydrocarbons, which possessed no functional groups, attached to the mercury. We were interested in testing the influence of substituents in the aromatic ring upon the progress of these photoreactions. The first example we chose was p-dianisylmercury, with carbon tetrachloride, chloroform, and methanol used as solvents. It was in these solvents that the most thoroughgoing investigation of the photoreactions of the other mercury derivatives had been made.

It is much harder to get a photoreaction of p-dianisylmercury than the reactions of the diaryl-substitutes of mercury tested previously. This is evidently due to the extremely sparing solubility of p-dianisylmercury in these organic solvents. p-Anisylmercury chloride and anisole were found in the reaction products of our tests in which chloroform was employed. This reaction may be pictured as follows. At first we have a dissociation into the p-anisyl and p-anisylmercury radicals:

$$(p\text{-}CH_3OC_6H_4)_2Hg + h\nu \rightarrow p\text{-}CH_3OC_6H_4Hg\cdot + p\text{-}CH_3OC_6H\cdot .$$

These radicals then react with the chloroform:

$$p\text{-}CH_3OC_6H_4Hg\cdot + CHCl_3 \rightarrow p\text{-}CH_3OC_6H_4HgCl + \cdot CHCl_2 ;$$

$$p\text{-}CH_3OC_6H_4\cdot + CHCl_3 \rightarrow CH_3OC_6H_5 + CCl_3\cdot .$$

It is seen that this photoreaction is quite similar to the reactions of Ar_2Hg in chloroform that we investigated previously. This analogy no longer applies, however, to the photoreaction in carbon tetrachloride, in which the end products are calomel, anisole, and a slight quantity of tarry products.

In our preceding papers we have shown that the phenyl and tolyl radicals detach chlorine from carbon tetrachloride, producing the corresponding chlorohydrocarbons and arylmercury chlorides. In the present instance, the radical does not react with the chlorine in the carbon tetrachloride, but detaches water from the methoxy group. We have often noticed reactions in which water is split off before chlorine is. The absence of these reactions in diphenylmercury is obviously attributable to the stability of the C—H bond in the benzene ring. It is therefore very highly likely that the hydrogen required for the formation of anisole comes from the CH_3- group rather than from the ring. A similar reaction was observed in the α-dinaphthylmercury: it is the second naphthyl radical in the α-naphthyl that yields naphthalene. This leads to the following set of reactions for p-dianisylmercury:

$$p\text{-}CH_3OC_6H_4Hg\cdot + CCl_4 \rightarrow p\text{-}CH_3OC_6H_4\cdot + HgCl + \cdot CCl_3;$$

$$2CH_3OC_6H_4\cdot \rightarrow CH_3OC_6H_5 + (CH_2OC_6H_4)_x.$$

The reaction was extraordinarily slow in methanol, probably due to the very sparing solubility of p-dianisylmercury in this solvent. But no tar was formed during the photoreaction, notwithstanding the extremely long exposure. The reaction products were found to contain anisole, mercury, and formaldehyde. All these substances could have been predicted from the reactions of Ar_2Hg with methanol investigated earlier, so that a reaction resembling that for the mercury derivative investigated previously may be advanced:

$$(p\text{-}CH_3OC_6H_4)_2Hg + CH_3OH \rightarrow 2CH_3OC_6H_5 + CH_2O + Hg.$$

These findings lead us to assert that a benzene ring containing the polar CH_3O- group exerted no major influence upon the course of the reaction, which is further evidence of the latter's radical nature. In ionic processes, the influence of the CH_3O- polar group ought to be very marked in the processes investigated.

EXPERIMENTAL

p-Dianisylmercury and carbon tetrachloride. 1.5 g of p-dianisylmercury was irradiated for 200 hours in 20 ml of carbon tetrachloride. The p-dianisylmercury was not fully dissolved in the carbon tetrachloride, so that the contents of the quartz test tube had to be vigorously shaken up from time to time. The reaction mass turned brown, with noticeable tarring.

After the reaction was over, the 0.92 g of the precipitate was filtered out. Hot benzene was used to extract from this precipitate 0.34 g of unreacted p-dianisylmercury, representing 22.7% of the amount used for the reaction; its melting point proved to be 199°, exhibiting no depression when mixed with the known pure product. The substance that was insoluble in benzene proved to be calomel (blackened by concentrated ammonia) weighing 0.58 g or 68.2% of the theoretical.

The filtrate was distilled on a water bath, and the distillate was nitrated. The nitro product proved to be p-nitroanisole with a m.p. of 54°, exhibiting no depression when mixed with pure p-nitroanisole.

p-Dianisylmercury and chloroform. 1.5 g of p-dianisylmercury was irradiated for 17 hours in 20 ml of chloroform, the solution turning yellow. A precipitate settled to the bottom of the test tube; it was filtered out and recrystallized from acetone. The resultant substance had a m.p. of 239° and proved to be p-anisylmercury chloride, its mixed melting point with the pure preparation exhibiting no depression. The yield was 0.89 g or 71.7% of the theoretical.

The filtrate was distilled on a water bath; the distillate was nitrated, yielding p-nitroanisole with a m.p. of 54°, which exhibited no depression with the pure substance. The distillation residue was the unreacted p-dianisylmercury, which had a m.p. of 199° after recrystallization from benzene and exhibited no depression when mixed with the pure product. It weighed 0.3 g or 20.0% of the initial quantity.

p-Dianisylmercury and methanol. 1.5 g of p-dianisylmercury was irradiated for 540 hours in 20 ml of methanol, the contents of the test tube being vigorously shaken up from time to time. The reaction mass remained colorless despite the prolonged radiation time. Metallic mercury settled out on the bottom of the test tube and was separated from the unreacted p-dianisylmercury by dissolving the latter in benzene. This yielded 0.34 g of metallic mercury, equivalent to 47.2% of the theoretical, and 0.69 g of unreacted p-anisylmercury, or 46.0% of the initial quantity. Its melting point was 199° after it had been recrystallized from benzene, exhibiting no depression when mixed with known p-dianisylmercury.

The filtrate was distilled on a water bath, the distillate being diluted with water, and the anisole extracted with carbon tetrachloride and nitrated. The melting point of the nitro compound was 54° (from alcohol); it exhibited no depression when mixed with pure p-nitroanisole. The alcoholic solution contained formaldehyde (fuchsinsulfurous acid, silver mirror).

SUMMARY

1. When a solution of p-dianisylmercury in carbon tetrachloride is irradiated, calomel and anisole are formed as the result of the detaching of hydrogen from the methoxy group.

2. Irradiation of p-dianisylmercury in chloroform yields p-anisylmercury chloride and anisole.

3. The photoreaction of p-dianisylmercury in methanol yielded anisole, mercury, and formaldehyde, though the reaction was extremely slow owing to the sparing solubility of the mercury compound.

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[2] See Consultants Bureau translation, p. 1485.

[3] See Consultants Bureau translation, p. 1489.

THE PHOTOREACTIONS OF ORGANIC COMPOUNDS OF MERCURY IN SOLUTIONS

X. THE REACTIONS OF DIMETHYLMERCURY

G. A. Razuvaev, Yu. A. Oldekop, and Z. N. Manchinova

In one of our previous papers [1] we cited the photoreaction of dimethylmercury with carbon tetrachloride, in which methylmercury chloride was produced. We have made a more thorough study of these reactions with diarylmercury derivatives. The reaction involves an initial dissociation of the organomercury compound into the RHg· and R· radicals.

After this paper of ours had appeared in print, several articles were published on the photoreactions of dimethylmercury. Gomer and Noyes [2], for example, investigated the photolysis of dimethylmercury at various temperatures and pressures. They took the initial process to be the formation of radicals, followed by a thermal reaction:

$$(CH_3)_2Hg \xrightarrow{h\nu} CH_3Hg\cdot + CH_3\cdot,$$

$$CH_3Hg\cdot \longrightarrow CH_3\cdot + Hg.$$

Ethane is formed by the collision of two methyl radicals or by the reaction of the methyl radical with dimethylmercury. In the latter case methane may also be produced by the detachment of hydrogen from a methyl radical of the dimethylmercury. Phibbs and de Darwent [3] made a study of the photoreaction of dimethylmercury with hydrogen in the gas phase, which takes place as follows:

$$(CH_3)_2Hg \xrightarrow{h\nu} 2CH_3\cdot + Hg,$$

$$CH_3\cdot + H_2 \longrightarrow CH_4 + H\cdot,$$

$$H\cdot + (CH_3)_2Hg \longrightarrow CH_4 + CH_3\cdot + Hg.$$

Ethane is formed in a side reaction:

$$CH_3\cdot + (CH_3)_2Hg \longrightarrow C_2H_6 + Hg + CH_3\cdot,$$

$$2CH_3\cdot + M \longrightarrow C_2H_6 + M.$$

At high temperatures the dimethylmercury is also decomposed thermally, a large part of the methyl radicals being "thermal".

Gomer [4] investigated the photo reaction of dimethylmercury with n-butane at 150-200°. The methyl radical initially formed during photolysis then reacted with the butane, detaching hydrogen from it:

$$CH_3\cdot + C_4H_{10} \longrightarrow CH_4 + C_4H_9\cdot$$

But all these papers deal with research in the gas phase.

Bawn and Whitby [5] suggested that organometallic compounds of silver and copper, which decompose very readily at low temperatures, be employed in investigating the reaction of the methyl radical in solutions. But when we decompose methylsilver, all we get is ethane, no reaction with the solvent taking place; the decomposition of methylsilver does not polymerize styrene or methyl methacrylate. All this is indisputable evidence that no methyl radical is present during the decomposition of methylsilver, which evidently is of an ionic nature. Methylcopper causes the polymerization of the above-mentioned substances, but this process is due to copper ions rather than to radicals. Methylcopper reacts with alcohol when no air is present without forming any aldehyde, the reaction being apparently an ionic one.

$$CH_3Cu + CH_3OH \longrightarrow Cu^+ + CH_4 + CH_3O\cdot .$$

The methyl radical may be secured in solutions by the Kharasch reaction [6], involving the addition of $CoCl_2$ or other metallic chlorides to organomagnesium chlorides. But this method requires the use of specific reaction conditions. The method of securing the methyl radical by decomposing acetyl peroxide in solutions

is extremely convenient, the equation being:

$$CH_3COOOCOCH_3 \longrightarrow CH_3\cdot + CO_2 + \cdot OCOCH_3.$$

Very recently, [7], however, doubts have arisen whether methyl radicals are the initial product of the decomposition of the peroxide. It may be that the peroxide is dissociated into radicals as follows:

$$CH_3COOOCOCH_3 \rightarrow 2CH_3CO_2,$$

yielding more highly stabilized alkoxy radicals, which then react with the solvent. Then the methyl radical is produced by the evolution of the CO_2 molecule.

That is why we believe that the photolysis of dimethylmercury is the most convenient reaction for investigating the behavior of methyl radicals in solutions.

The initial reaction is the detaching of one methyl group:

$$(CH_3)_2Hg \xrightarrow{h\nu} CH_3Hg\cdot + CH_3.$$

That a methylmercury radical has been formed is proved beyond the shadow of doubt by its reactions with halogen-containing solvents. Like an ArHg radical, the CH_3Hg radical detaches a halogen atom from the solvent. Thus, in experiments run in a carbon tetrachloride or chloroform solution, methylmercury chloride is produced, methylmercury iodide being formed in a methyl iodide solution. In solvents that contain no halogen, methylmercury breaks down further into mercury and a methyl radical.

In a methanol or chloroform solution the methyl radical reacts with hydrogen, giving rise to methane, formaldehyde being detected in the methanol solution and hexachloroethane in the chloroform solution. Thus, the outlines of the photoreactions for dimethylmercury remain the same as those we put forward earlier for Ar_2Hg.

When the dimethylmercury reaction is carried out in methyl iodide, methylmercury iodide is produced, as has been stated above. Thus two methyl radicals are set free: one from the dimethylmercury and the other from the methyl iodide. We might, therefore, expect ethane to be formed:

$$CH_3HgCH_3 + ICH_3 \longrightarrow CH_3HgI + C_2H_6.$$

The gas evolved in the reaction is methane, however. Hence, the methyl radicals react with the solvent, detaching hydrogen from it; thus this reaction is similar to the one described for the photoreaction of diphenylmercury with methyl iodide in a methanol solution [8]. Only when the photoreaction of dimethylmercury was carried out in a carbon tetrachloride solution was no methane formed. In this case, the methyl radical reacted by detaching a chlorine atom from the solvent, producing methyl chloride.

It is worthy of note that the methyl radicals do not detach hydrogen from benzene or 2,2,4-trimethylpentane under the conditions we have described, metallic mercury and ethane being produced in photoreactions in these solvents. The reactions are much harder to carry out than in other solvents. When dimethylmercury is irradiated in a solution consisting of a methanol– carbon tetrachloride mixture, the methyl mercury and methyl radicals formed at the start of the reaction react with different constituents of the solvent. The equations for the reaction are:

$$CH_3Hg\cdot + CCl_4 \longrightarrow CH_3HgCl + CCl_3\cdot,$$

$$2CCl_3\cdot \longrightarrow Cl_3CCCl_3,$$

$$2CH_3\cdot + CH_3OH \longrightarrow 2CH_4 + CH_2O.$$

This experiment proves that the methyl radicals must exist in the solution for some time, reacting selectively.

EXPERIMENTAL

Dimethylmercury and methanol. A solution of 1.5 g of dimethylmercury in 20 ml of methanol was placed in a quartz test tube connected to a gas buret and irradiated with a mercury quartz lamp for 40 hours. Gas was evolved during the reaction, 215 ml being collected. Gas analysis indicated that the gas was methane. The evolution of metallic mercury in the photolysis of the dimethylmercury during the reaction was highly interesting: the mercury settled out continuously as extremely small drops on the bottom of the test tube, so that a substantial drop of mercury had accumulated on the test-tube bottom by the end of the reaction. The drop was filtered out; it weighed 1.0 g (76% of the theoretical yield). Formaldehyde was found in the filtrate (dimedon derivative with a m.p. of 189°).

Dimethylmercury and 2,2,4-trimethylpentane. A solution of 1.5 g of dimethylmercury in 7 ml of 2,2,4-trimethylpentane was irradiated for 30 hours, during which time 63 ml of a gas that proved to be ethane was collected. The metallic mercury produced during the reaction was filtered out; it weighed 0.55 g, equivalent to 42% of the theoretical.

Dimethylmercury and benzene. 1.5 g of dimethylmercury was irradiated in 20 ml of benzene for 40 hours, 37 ml of gas being collected during this time. Analysis indicated that the gas was ethane. The metallic mercury that settled out during the reaction was filtered out; it weighed 0.4 g, equivalent to 31% of the theoretical.

Dimethylmercury and chloroform. A solution of 1.5 g of dimethylmercury in 7 ml of chloroform was irradiated for 60 hours, during which time 120 ml of gas was collected. Gas analysis indicated that the gas was methane. A white crystalline substance with a slight gray coating of metallic mercury formed inside the test tube. The precipitate was filtered out and recrystallized from dichloroethane (m.p. 170°), exhibiting no depression with pure methylmercury chloride. The filtrate was distilled with steam, a white crystalline substance with the odor of camphor solidifying in the condenser. It had a m.p. of 184° (in a sealed capillary) after having been sublimed over concentrated sulfuric acid, exhibiting no depression of the melting point when mixed with pure hexachloroethane. Distillation of the residue yielded some more methylmercury chloride, the aggregate weight of methylmercury chloride being 1.35 g, or 80% of the theoretical.

Dimethylmercury and methyl iodide. A solution of 1.5 g of dimethylmercury in 7 ml of methyl iodide was irradiated for 50 hours, 132 ml of gas being collected during that time. Gas analysis proved that the gas was methane. The precipitate formed during the reaction was filtered out; traces of metallic mercury and mercuric iodide were visible in it. The precipitate was recrystallized from alcohol (m.p. 145°), exhibiting no depression of the melting point with pure methylmercury chloride. The filtrate was distilled, the residue consisting of methylmercury chloride, with a m.p. of 145°, the total weight of the latter compound being 1.9 g, or 85% of theory.

Dimethylmercury and carbon tetrachloride. 1.5 g of dimethylmercury in 3 ml of carbon tetrachloride was irradiated for 50 hours. The precipitate (in which traces of mercury were observed) was filtered out and recrystallized from dichloroethane (m.p. 170°), exhibiting no depression of the melting point when mixed with pure methylmercury chloride. During the experiment, 8 ml of gas was collected and dissolved in methanol. This solution yielded a precipitate of silver chloride when allowed to stand with a solution of silver nitrate. No methane was found.

The filtrate was distilled, hexachloroethane solidifying in the condenser; the hexachloroethane was extracted and sublimed over sulfuric acid; its m.p. was 184°, exhibiting no depression when mixed with the pure preparation. The residue contained methylmercury chloride (m.p. 170°), exhibiting no depression of the melting point when mixed with the pure product. The total weight of methylmercury chloride was 1.8 g, or 80% of the theoretical yield.

Dimethylmercury in methanol and carbon tetrachloride. A solution of 1.5 g of dimethylmercury in 3 ml of methanol and 3 ml of carbon tetrachloride was irradiated for 50 hours, 80 ml of gas being collected during that time. Analysis proved that the gas was methane. The crystalline precipitate, which contained traces of metallic mercury, was filtered out and recrystallized from alcohol (m.p. 170°); the mixed melting point with pure methylmercury chloride exhibited no depression. The precipitate weighed 1.8 g, or 80% of the theoretical. The filtrate was distilled, formaldehyde being found in the distillate (dimedon derivative with a m.p. of 189°). Hexachloroethane (m.p. 184°) was extracted from the condenser; its mixed melting point with the pure product exhibiting no depression.

SUMMARY

1. It has been proved that dimethylmercury is broken down by photolysis into the $CH_3^{\bullet}$ and $CH_3Hg^{\bullet}$ radicals; the reaction is the same as that for the aryl compounds of mercury.

2. Dimethylmercury reacts with methanol when irradiated by ultraviolet light, yielding methane, mercury, and formaldehyde.

3. The photoreaction of dimethylmercury with chloroform yields methylmercury chloride, methane, and hexachloroethane.

4. When dimethylmercury is irradiated in methyl iodide solution, it yields methylmercury chloride and methane.

5. Irradiation of dimethylmercury dissolved in carbon tetrachloride yields methylmercury chloride, methyl chloride, and hexachloroethane.

6. When the photoreaction is carried out with dimethylmercury dissolved in methanol and carbon tetrachloride, photolysis yields the $CH_3Hg^{\cdot}$ and methyl radicals, which react with different components of the solution. The first radical reacts with the carbon tetrachloride, yielding methylmercury chloride, while the methyl radical reacts with the methanol to yield methane.

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THE REACTION OF DIPHENYLMERCURY WITH METALLIC CHLORIDES THAT DO NOT FORM STABLE ORGANOMETALLIC COMPOUNDS

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The radical—halogen reaction is a general reaction for organoelemental compounds of considerable practical interest, inasmuch as it makes possible the synthesis of any organoelemental compound. Organometallic compounds of mercury may be used successfully for this purpose, particularly when we have to synthesize an organoelemental compound containing a functional group. The reaction of organomercury compounds with halogen derivatives was used to prepare organic compounds of boron, thallium, silicon, tin, phosphorus, arsenic, antimony, bismuth, and iodine [1].

When metallic halides which do not form organometallic compounds are used in the reaction, the course of the reaction changes sharply. The changes produced in the reactions of organomagnesium and organolithium compounds by the addition of small amounts of cobalt, iron, and manganese, due to the formation of unstable organometallic compounds that decompose readily, yielding free radicals

$$RMgCl + CoCl_2 \longrightarrow RCoCl + MgCl_2;\quad RCoCl \longrightarrow R^{\cdot} + CoCl^{\cdot},$$

have been investigated in the greatest detail [2].

Recently some organocopper compounds have been produced in a Grignard reaction from cobalt chloride [3]. The singular chemical reactions of organomagnesium and organolithium compounds are also explainable by the ensuing processes involving the R· and CoCl· radicals.

We felt it would be of interest to check the course of the reactions with cobaltous, ferric, and cupric chlorides, as well as with other organometallic compounds in order to determine how far these processes are common to them all. We confined ourselves to organomercury compounds and have already noted many examples of reactions that involve a stage in which free radicals are formed [4]. Diphenylmercury often reacts with dissociation into radicals:

$$(C_6H_5)_2Hg \longrightarrow C_6H_5Hg^{\cdot} + C_6H_5^{\cdot}$$

Characteristic of the phenyl radical are the reactions in which it is saturated with hydrogen, coming from the solvent. When alcoholic solutions of diphenylmercury are heated, for example, the phenyl radical reacts with the alcohol, yielding benzene and phenol ether [5]. The photoreactions of diphenylmercury with alcohols, ethylcellosolve [6], dioxane [7], and morpholine are like the preceding ones. In every case the phenyl radical is converted into benzene by detaching hydrogen from the solvent.

In the present research we have investigated the reaction of diphenylmercury with cobaltous chloride, ferric chloride, and cupric chloride in solutions of ethylcellosolve, dioxane, and morpholine. When anhydrous cobaltous chloride is added to a cooled solution of diphenylmercury in ethylcellosolve and the mixture is cooled, crystals of phenylmercury chloride and a cobalt compound settle out. Benzene and acetaldehyde were found in the ethylcellosolve solution. The phenylmercury chloride was removed from the precipitate by treating the latter with dichloroethane. The residue consisted of the cobalt compound, which was insoluble in water, though readily soluble in acids. Cobalt hydroxide was precipitated from the acid solution by an alkali, part of the solution was driven off, the presence of ethyl alcohol in the distillate being proved by an iodoform test. A chlorine content equivalent to one chlorine atom to two cobalt atoms was proved in the resultant compound. It was thus found that the reaction involves the splitting out of one phenyl radical out of the diphenylmercury, the radical reacting with the solvent, ethylcellosolve, to produce benzene and acetaldehyde. The reaction may be pictured as follows:

$$(C_6H_5)_2Hg + CoCl_2 \longrightarrow C_6H_5HgCl + C_6H_5CoCl;\quad C_6H_5CoCl \rightarrow C_6H_5^{\cdot} + CoCl^{\cdot};$$

$$C_6H_5^{\cdot} + CoCl^{\cdot} \longrightarrow C_6H_6 + CH_3CHO + ClCo(OC_2H_5).$$

The composition of the resultant cobalt derivatives was close to that given by the formula $Co_2ClO_2C_2H_5$, however. The formation of this compound may be hypothetically represented by the following equation:

added to 5.0 g of $(C_6H_5)_2Hg$ in 25.5 g of morpholine, and the solution was refluxed for 1 hour. Phenylmercury chloride settled out as the solution cooled. The precipitate was filtered out, and the phenylmercury chloride was separated from the cobalt compound in the usual manner. Distillation of the filtrate yielded a fraction passing over up to 110°, from which a benzene layer separated when it was diluted with water. Free mercury was also detected among the reaction products. This yielded: 0.4 g of phenylmercury chloride with a m.p. of 253° (from acetone), 0.35 g of crude benzene, from which we prepared m-dinitrobenzene with a m.p. of 90°, and 0.8 g of mercury. The mixed melting points of the m-dinitrobenzene and the phenylmercury chloride exhibited no depression when mixed with the pure products.

8. Reaction of diphenylmercury with morpholine and ferric chloride. 2.0 g of $FeCl_3$ was dissolved in 18.0 g of morpholine, the dissolution being very violent, with the evolution of considerable heat. Then 5.0 g of $(C_6H_5)_2Hg$ was added to the solution, and the whole was refluxed for 3 hours. A gray incrustation of metallic mercury separated out during heating. The contents of the flask crystallized upon cooling. The tarry liquid portion of the reaction mixture was decanted and distilled with steam, a layer of benzene appearing in the condensate. The tarry residue was dissolved in dilute hydrochloric acid, metallic mercury settling on the bottom of the flask. This yielded 0.87 g of mercury (30.8% of the theoretical) and 0.77 g of benzene (34.9% of the theoretical), from which we prepared m-dinitrobenzene with a m.p. of 90°. The mixed melting point of the latter compound exhibited no depression with a pure sample. No phenylmercury chloride was found.

9. Reaction of diphenylmercury with morpholine and cupric chloride. 2.0 g of anhydrous $CuCl_2$ was added to 5.0 g of $(C_6H_5)_2Hg$ in 18.0 g of morpholine, and the mixture was refluxed for 3 hours. As the solution was heated, its dark-green color disappeared, but reappeared upon cooling. Metallic mercury settled on the bottom of the flask. After the solution had cooled, it was decanted from the mercury and distilled with steam, a benzene layer separating from the condensate. This yielded 1.4 g of benzene (63.5% of the theoretical), from which we prepared m-dinitrobenzene with a m.p. of 88°. Its mixed melting point with a pure sample exhibited no depression. In addition, we secured 2.4 g of metallic mercury (84.9% of the theoretical).

From the reaction products of diphenylmercury with morpholine we isolated a substance that partially sublimed, and crystallized from the individual fractions (during fractionation of the liquid portion of the reaction product) as well as from the aqueous solutions after the benzene had been eliminated. It sublimed readily; m.p. 115° (in a sealed capillary); it was freely soluble in water, and sparingly so in benzene. It dissolved violently in dilute acids (HCl), giving off CO_2 and yielding morpholine hydrochloride with a m.p. of 174°. Its mixed melting point with the salt prepared from pure morpholine exhibited no depression. Reacting it with methyl iodide yielded morpholine methiodide:

Found %: I 55.36, 54.04. $C_5H_{12}NOI$. Calculated %: I 54.16.

Found %: H 8.12, 8.26; C 49.20, 49.00; N 12.89, 12.82; $C_9H_{18}O_4N_2$. Calculated %: H 8.26; C 49.50; N 12.83.

The analysis and properties of this substance indicated that it was morpholine carbonate, which was borne out by the preparation of the carbonate by reacting CO_2 with morpholine. The carbonate sublimed readily and fused at 114-115° in a sealed capillary.

SUMMARY

1. When a solution of diphenylmercury in ethylcellosolve or dioxane is heated with cobaltous chloride or ferric chloride, it yields phenylmercury chloride and benzene, due to the reaction of the phenyl radical with the solvent.

2. When a solution of diphenylmercury in ethylcellosolve or dioxane is heated with cupric chloride, the reaction yields phenylmercury chloride, chlorobenzene, and cuprous chloride.

3. When a solution of diphenylmercury in morpholine is heated with ferric chloride, cupric chloride, or cobaltous chloride, benzene is formed and metallic mercury is thrown down. The reaction probably involves reducing processes that occur when complex salts of metallic chlorides and morpholine are heated.

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THE SYNTHESIS AND THE POLYMERIZABILITY OF RING-HALOGENATED DERIVATIVES OF STYRENE

SYNTHESIS OF RING-DICHLORINATED STYRENES

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There are not many papers in the literature on the synthesis and properties of the dichlorostyrenes [1]. Of all the possible isomers of the dichlorostyrenes, it is the synthesis of 3,4-dichlorostyrene that is described in greatest detail [2], though a method of synthesis is given for 2,5-dichlorostyrene that starts out with materials that are extremely difficult to procure. We have endeavored to make a study of the synthesis of the dichlorostyrenes and to find a general method of preparing the isomeric dichlorostyrenes, viz., 2,4-dichlorostyrene; 2,5-dichlorostyrene; and 3,4-dichlorostyrene.

EXPERIMENTAL

I. Synthesis of 2,5-Dichlorostyrene

1. Preparation of 2,5-dichloroacetophenone. 168.0 grams of p-dichlorobenzene was mixed with 308.0 g of anhydrous aluminum chloride, and 180.0 g of acetyl chloride was added. The mixture was heated to 130° on an oil bath for 3 hours. The reaction mixture was decomposed by pouring ice and dilute HCl over the mixture, after which it was extracted with CCl_4, washed with 10% alkali and with water, and dried. The CCl_4 was driven off, and the residue fractionated in vacuo. 2,5-Dichloroacetophenone has a b.p. of 104-105° at 2 mm and 245-247° at atmospheric pressure; its m.p. is 9-10°. The yield was 102.0 g, or 46% of the theoretical.

2. Preparation of 2,5-dichlorophenylmethylcarbinol. 50.0 g of 2,5-dichloroacetophenone was dissolved in 350 ml of isopropyl alcohol, 75 ml of a solution of aluminum alcoholate was added, and the whole was heated on a water bath for 6 hours. This drove off all the acetone formed and a large part of the isopropyl alcohol. The residue was chilled with ice, acidulated with 10% HCl, extracted with benzene, washed, and dried, after which the benzene was driven off, and the residue was fractionated in vacuo, yielding 42.0 g of 2,5-dichlorophenylmethylcarbinol (84% of the theoretical) with a b.p. of 117° at 2 mm and a m.p. of 60-62°.

3. Synthesis of 2,5-dichlorostyrene. 2,5-Dichlorostyrene was synthesized, with a yield that was 50-60% of the theoretical, by dehydrating 2,5-dichlorophenylmethylcarbinol above Al_2O_3 at 350-400° and 120 mm mercury column. 2,5-Dichlorostyrene is an aromatic, colorless liquid (with the odor of styrene); its b.p. is 92-94° at 5 mm and 72-73° at 2 mm; its specific gravity at 20° is 1.246. It is readily polymerized.

II. Synthesis of 2,4-Dichlorostyrene

The 2,4-dichlorostyrene was synthesized by the same procedure as that used for the synthesis of the 2,5-dichlorostyrene, but starting out with m-dichlorobenzene. The yield of 2,4-chloroacetophenone, with a b.p. of 122-124° (12 mm) was 50% of the theoretical. The 2,4-dichloroacetophenone was reduced to a carbinol, the yield being 60% of the theoretical. The b.p. of 2,4-dichlorophenylmethylcarbinol was 126-128° (7 mm). Dehydrating the 2,4-dichlorophenylmethylcarbinol yielded 2,4-dichlorostyrene, the yield being 30% of the theoretical.

2,4-Dichlorostyrene is a colorless, aromatic liquid with a b.p. of 80-81° at 6 mm and a specific gravity of 1.249 at 20°. It is readily polymerized.

III. Synthesis of 3,4-Dichlorostyrene

The conditions used in synthesizing 3,4-dichlorostyrene were the same as those employed for 2,5-dichlorostyrene, but o-dichlorobenzene was employed as the initial material. The yield of 3,4-dichloroacetophenone, with a b.p. of 135° (12 mm) and a m.p. of 74°, was 64.5% of the theoretical. Reducing the

3,4-dichloroacetophenone gave us 73% of the theoretical yield of 3,4-dichlorophenylmethylcarbinol, with a b.p. of 126-127° (2 mm) and a specific gravity of 1.311 at 20°. Dehydrating the 3,4-dichlorophenylmethylcarbinol produced 75% of the theoretical yield of 3,4-dichlorostyrene.

3,4-Dichlorostyrene is a colorless, aromatic liquid with a b.p. of 92° at 6 mm and a specific gravity of 1.256 at 20°. It is harder to polymerize than the 2,5- and 2,4-dichlorostyrene.

SUMMARY

A general method has been developed for synthesizing 2,5-dichlorostyrene, 2,4-dichlorostyrene, and 3,4-dichlorostyrene.

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ISOMERIZATION OF SALTS OF CINNAMYLIDENEANILINE

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The so-called "Schiff's bases" are not always basic. Many compounds of the ArCH=NAr type, whose amine rings contain electronegative substituents, do not manifest the slightest tendency to salt formation and are actually insoluble in acids. Yet, some of them are weakly basic, forming unstable addition products with strong acids. Lastly, fairly stable salts may be secured in some cases, able to stand recrystallization even from boiling water.

Reference is made in the chemical literature to the high stability of the addition product of hydrogen chloride to cinnamylideneaniline, which is mentioned, more particularly, by Izmailsky [1].

This salt, $C_6H_5CH{=}CH{-}CH{=}N{-}C_6H_5{\cdot}HCl$, is readily prepared by the direct action of strong hydrochloric acid upon the freshly prepared anil, followed by recrystallization of the reaction product from hot water. As the aqueous solution cools, beautiful golden-yellow needles with a m.p. of 147-148° settle out (we have found the m.p. of this substance to be 151-152°).

Synthesizing the analogous salt of orthomethylcinnamylideneaniline (m.p. 93-95°) from orthotoluidine, we observed an appreciable difference in the behavior of these salts and in their external qualities. The anil salt had a lighter, golden "quinone" color and reacted less readily with a soda solution, whereas the salt of the orthomethyl anil could be crystallized from hot water only with a poorer yield, due to its pronounced hydrolysis into its original constituents, as is highly characteristic of many anil salts. This led us to suppose that the anil is not the primary reaction product, but rather the end product of some transformation occurring during heating or recrystallization. As a matter of fact, when freshly prepared cinnamylideneaniline was triturated with a slight excess of hydrochloric acid (sp.gr. 1.19) at room temperature, we secured an orange-colored mass, which had a m.p. of 80-82° after it had been carefully washed with water and dried on the filter. The substance greatly resembled the salt of orthomethylcinnamylidene. It reacted vigorously with a soda solution, was much more soluble in water than the substance with a m.p. of 151-152°, threw down a pronounced precipitate with $AgNO_3$, and behaved like a typical salt in all other respects. The compound displayed a positive double-bond reaction with permanganate.

It may well be that the most interesting property of this substance is its instability. It is transformed into the substance with a m.p. of 151-152° within the space of about 24 hours. This is why the low-melting salt was not detected by previous investigators, it being completely transformed into the high-melting product when recrystallized from hot water.

We have been able to observe this transition directly, utilizing the differing solubilities of the salts in water. This was done by placing a test tube containing an aqueous solution of the low-melting form saturated in the cold in a beaker of water. As the beaker was slowly heated on a water bath at 55°, the contents of the test tube quickly turned cloudy, throwing down crystals of another, less soluble form, which redissolved as heating was continued; when the solution was cooled, nothing but the substance with a m.p. of 151-152° settled out.

The paramethylanil yielded different results: no matter what experimental conditions were employed, the only salt it yielded was one with a m.p. of 168-170°, whose properties greatly resembled those of the high-melting anil salt, especially in its being able to stand recrystallization from hot water without suffering any change in its properties or its melting point. The salt of the paramethylanil exhibits no tendency toward conversion into another form.

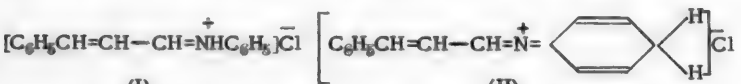
We also found that the property of forming two kinds of salts is not peculiar to cinnamylideneaniline. Our experimental data are listed in the following table.

TABLE

Amine	Acid	M.p.	
		Low-melting form	High-melting form
Aniline	Hydrochloric	80-82°	151-152°
p-Toluidine	Hydrochloric	Not formed	168-170°
o-Toluidine	Hydrochloric	93-95°	Not formed
p-Bromoaniline	Hydrobromic	101-103	143-144
p-Chloroaniline	Hydrochloric	Not tested	158-159
p-Anisidine	Hydrochloric	Not formed	158-159
m-Aminophenol	Hydrochloric	105	Not formed

As with the orthomethylanil, the other low-melting salts are dark-yellow or orange, are readily hydrolyzed into an aldehyde and an amine when boiled, react vigorously with a soda solution, liberating carbon dioxide, and are freely soluble in water. The high-melting isomers, on the other hand, are golden-yellow, remain practically unhydrolyzed when boiled, react less strongly with a soda solution (sometimes the only way to secure the base is to let the salt stand for a long time in a soda solution), and are much less soluble in water.

The behavior and properties of the salts indicate that their formulas are:



(I) Low-melting modification

(II) High-melting modification

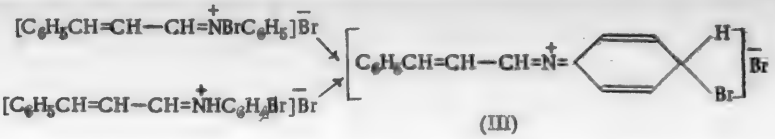
We investigated the bromination of cinnamylideneaniline to secure experimental confirmation of the foregoing structure.

This bromination was first performed by Schiff [2], who secured a yellow powder, which he stated had a m.p. of 175° after recrystallization from alcohol and was a dibromide, according to his analysis. Schiff assigned it the structure of $C_6H_5CHBr-CHBr-CH=N-C_6H_5$ for no apparent reason whatsoever.

James and Judd [3] returned to this problem. By reacting bromine with cinnamylideneaniline dissolved in glacial acetic acid they secured an orange-yellow powder with a m.p. of 196-198°, which was decomposed by sodium ethylate into parabromoaniline and cinnamaldehyde. This led the authors to conclude that Schiff's formula was wrong, as the cinnamaldehyde was regenerated, although they themselves proposed to refrain from settling the problem of the structure of the dibromide conclusively, confining themselves to the formula $C_6H_5-CH=CH-CH=N-C_6H_5 \cdot Br_2$.

We repeated the bromination of cinnamylideneaniline, again doing so in a glacial acetic acid solution. The very first batches of the halogen produced the strong precipitation of an orange precipitate, which was filtered out after the end of the reaction, washed with glacial acetic acid, and dried in air. The substance fused to a red liquid at 166-167°. Its properties resembled those of the low-melting salts of cinnamylideneaniline, being freely soluble in water, insoluble in ether, evolving carbon dioxide violently when reacted with soda, being partially hydrolyzed when boiled in water, yielding cinnamaldehyde, but undergoing very rapid change when stored. When recrystallized from hot water, it yielded a conversion product, a substance with a m.p. of 143-144°. The hydrobromide of parabromocinnamylideneaniline, prepared from the parabromoanil and hydrobromic acid (m.p. 101-103°) and converted into the high-melting form (m.p. 143-144°) by recrystallization, exhibited no depression of the melting point when mixed with the substance we had synthesized; their properties were wholly alike, and, hence, they were identical.

The fact that the dibromide of cinnamylideneaniline and the hydrobromide of the parabromoanil prepared in the cold were two different substances but both exhibited the properties of salts and both were converted into the same substance when recrystallized is convincing evidence that their structure must be that of (III):



(III)

It is not impossible that the low-melting form of the hydrobromide of the parabromoanil occurs as a transient intermediate product of the conversion of the dibromide. Another variant of the dibromide's structure is theoretically possible: $C_6H_5CH{=}CH{-}CHBr{-}NBr{-}C_6H_5$, but it must be discarded. The saltlike nature of the substance is prime evidence against this structure.

We have found the same state of affairs to prevail when the anil is chlorinated. The hydrochloride of parachlorocinnamylideneaniline with a m.p. of 158-159° (after recrystallization from water) corresponds with the cinnamylideneaniline dichloride synthesized by Staudinger [4] in all its properties. This justifies our adopting the structure of the two forms of the hydrohalides of cinnamylideneaniline set forth above.

EXPERIMENTAL

1. Cinnamylideneaniline. 9.3 g (0.1 mole) of freshly distilled aniline was dissolved in 15 ml of 96% alcohol. 13.2 g (0.1 mole) of cinnamaldehyde diluted with an equal quantity of alcohol, was added to the solution. The mixture was gently heated, turning into a yellow mass within a few minutes. After recrystallization from alcohol the substance fused into a transparent liquid at 106-107°. The yield was 80% of the theoretical.

4.271 mg substance: 0.265 ml N_2 (19°, 751 mm). 3.914 mg substance: 0.216 ml N_2 (19°, 766 mm). Found %: N 7.17, 6.50. $C_{15}H_{13}N$. Calculated %: N 6.76.

Cinnamylideneaniline is an unstable substance, quickly turning red when exposed to air and acquiring an intensive isonitrile odor. For this reason a freshly prepared product was employed in all our subsequent experiments. The anil is decomposed even faster when exposed to sunlight. It does not distil with steam, but is gradually hydrolyzed, so that the distillate always is found to contain aniline and cinnamaldehyde plus (at times) a minute amount of cinnamic acid. Analysis after storage for two years in a colorless bottle gave no indication of a homogeneous substance. Analysis for nitrogen after one month of storage yielded the following results:

3.800 mg substance: 0.286 ml N_2 (17°, 765 mm). 3.743 mg substance: 0.250 ml N_2 (16°, 786 mm). 3.547 mg substance: 0.243 ml N_2 (17°, 744 mm). Found %: N 8.92, 7.86, 7.93. $C_{15}H_{13}N$. Calculated %: N 6.76. In other words, it is the part of the compound that is poorer in nitrogen that decomposes.

An attempt to secure the anil in an alkaline medium was unsuccessful, the greenish product that resulted turning into tar when we tried to recover it in the pure state.

2. The hydrochloride of the anil. The best of all the methods tried out for synthesizing a salt of cinnamylideneaniline consists of triturating the freshly prepared anil with a slight excess of hydrochloric acid (sp.gr. 1.19) at room temperature. This yielded an orange-colored mass, which was washed in as little water as possible and dried between sheets of filter paper and then for a long time in air, after which its m.p. was 80-82°. The salt readily undergoes change in storage, ultimately turning into a substance with a m.p. of 149-151° after standing for 24 hours. This change takes place in the solid phase in a desiccator above H_2SO_4, in the open air, and in a sealed ampoule. It takes place most rapidly when heated in a solvent, especially in water.

Numerous analyses of the substance failed to yield satisfactory results, the percentage of nitrogen fluctuating from 4.5% to 5.5%, as against the 5.71% calculated for $C_{15}H_{13}N{\cdot}HCl$.

The substance is freely soluble in water, hydrolyzing partially when its aqueous solution is heated and yielding cinnamaldehyde (phenylhydrazone, m.p. 168°) and aniline (bleaching powder reaction), the residue turning into the high-melting product. It reacts like a true salt with carbonates, liberating CO_2 as well as the original anil.

This substance may be secured by directly reacting cinnamaldehyde with aniline in concentrated hydrochloric acid. In one instance it was secured quantitatively by pouring a mixture of 13.2 g of cinnamaldehyde and 10 ml of hydrochloric acid (sp.gr. 1.19) into an equimolecular quantity of aniline.

A saturated NaCl solution throws down the salt from its aqueous solutions.

3. Isomerization product of the anil hydrochloride. The substance produced by recrystallizing the cinnamylideneaniline hydrochloride, known in the literature as the anil salt with a m.p. of 147-148°, actually has a m.p. of 151-152°. Its color is golden-yellow. It is much less soluble in water than the original substance, and it reacts very slowly with a soda solution. Its crystals turn green when exposed to air and exhibit an excessively low value for the percentage of nitrogen.

4.643 mg substance: 0.204 ml N_2 (14°, 757 mm). Found %: N 5.21. $C_{15}H_{13}N \cdot HCl$. Calc.%: N 5.75.

When this salt is reacted with alkalis or soda, it yields a slightly greenish, almost colorless base with a m.p. of 110°. The base is completely stable in air and has no isonitrile odor. When it is recrystallized from alcohol or merely heated, it is transformed into the usual form of cinnamylideneaniline with a m.p. of 106-107°. In none of its other properties does it differ from cinnamylideneaniline.

Both of these salts are soluble in alcohol and acetone and insoluble in ether. When reduced with tin in a hydrochloric medium, both of them break down into their constituents: aniline and cinnamaldehyde.

4. Paramethylcinnamylideneaniline and orthomethylcinnamylideneaniline and their salts. The paramethylanil was prepared in alcohol by pouring together equimolecular quantities of paratoluidine and cinnamaldehyde; its m.p. was 83° after recrystallization from alcohol. In contrast to the anil proper, it does not acquire the odor of an isonitrile upon standing, although it does undergo a change.

We were able to isolate the salt only in one form. It had a m.p. of 168-170° whether isolated in the cold or after recrystallization from alcohol.

3.814 mg substance: 0.178 ml N_2 (17°, 753 mm). Found %: N 5.44. $C_{16}H_{14}N \cdot HCl$. Calc.%: N 5.44

The base regenerated from the salt had a m.p. of 83-84°, but, as in the case of the anil, its color was not the original yellow, but rather slightly greenish, and underwent no change even when kept for months exposed to air. It may be supposed that the substance is converted into the usual form that is stable in storage, even before it reaches its melting point, as we have seen in recrystallization from alcohol, for example.

The orthomethylanil was prepared similarly; its m.p. was 73°. This substance, on the other hand, yields nothing but the low-melting salt, m.p. 93-95°. It is largely hydrolyzed when recrystallized from water, but again melts at 93-95°.

4.000 mg substance: 0.194 ml N_2 (16°, 762 mm). Found %: N 5.67. $C_{16}H_{15}N \cdot HCl$. Calc.%: N 5.44.

The salts of both of these methylanils are likewise unstable, undergoing change when exposed to air, finally being converted into an amorphous mass.

5. Paramethylcinnamylideneaniline methiodide. 2.21 g (0.01 mole) of paramethylcinnamylideneaniline was dissolved in ether to which a few drops of benzene had been added. Twice the theoretical quantity of methyl iodide was then added to the solution. Fifteen days later the red-brown crystals were filtered out and boiled with ethyl alcohol. The substance fused at 196°, without decomposition, to a black liquid. It is extremely stable, withstanding brief heating over a naked flame, but then decomposing with the evolution of yellow fumes. It is nearly insoluble in alcohol, remaining unchanged in boiling water. It does not react with bicarbonate in the cold or when boiled. Microscopic examination showed cubic prisms.

3.347 mg substance: 0.120 ml N_2 (18°, 745 mm). Found %: N 3.74. $C_{17}H_{18}NI$. Calc.%: N 3.85.

6. Brominating cinnamylideneaniline. 4 14 g (0.02 mole) of the anil was dissolved in 25 ml of glacial acetic acid. A solution of 3.6 g of bromine in glacial acetic acid was gradually added to the cherry-red solution, causing the precipitation of a deposit that resembles the anil salts. The m.p. was 166-167° after washing with acetic acid and drying on the filter. It dissolves in water like a typical anil salt and is hydrolyzed when its solution is heated, liberating cinnamaldehyde. It changes fairly rapidly when exposed to air and yields a base when reacted with bicarbonate.

Like all the anil salts, it does not yield satisfactory results upon analysis, owing to its comparatively rapid decomposition.

4.086 mg substance: 0.108 ml N_2 (16°, 772 mm). Found %: N 3.17. $C_{15}H_{13}NBr_2$. Calc.%: N 3.81.

Two days later analysis yielded different findings:

3.800 mg substance: 0.173 ml N_2 (16°, 779 mm). Found %: N 4.36.

Recrystallizing the salt from water converted it into another form, with a m.p. of 143-144°, which proved to be parabromocinnamylideneaniline hydrobromide.

The latter salt was synthesized by a different method for the sake of comparison.

We first synthesized the parabromoanil from cinnamaldehyde and parabromoaniline (m.p. 120-121°) and then secured the salt itself, with a m.p. of 101-103°, by reacting the product with hydrogen bromide in the cold. This salt is readily transformed into the higher-melting form, its m.p.being 143-144° after recrystallization from hot water.

The appearance and the properties of this salt and of the cinnamylideneaniline dibromide are identical. Their mixed melting point is 143-144°, without depression.

7. The p-chloroanil's hydrochloride. The hydrochloride of the parachloroanil was synthesized analogously. Its m.p. was 158-159° after recrystallization from hot water, which corresponds to the "dichloride" of cinnamylideneaniline (m.p. 158°) described in the literature and prepared by chlorinating the anil directly The salt is likewise unstable in air, gradually undergoing a change, though recrystallization,even from boiling water, yields extremely minute quantities of cinnamaldehyde and the amine, i.e., practically no hydrolysis takes place. All of its properties and its appearance are the same as those of the anil's dichloride.

The action of alkalies and of soda regenerates the initial parachloroanil in a slightly greenish form, which is as stable in air as the corresponding forms of the other anils described above.

SUMMARY

1. A study has been made of the isomerization of salts of cinnamylideneaniline.

2. Formulas are suggested for the structure of the resultant products.

3. A study has been made of the bromination of cinnamylideneaniline and the structure of the resultant substances has been demonstrated.

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THE SYNTHESIS OF m-AMINO(HYDROXY)-PHENYL-β-(METHYLAMINO)-ETHANOLS AND THE CATALYTIC REDUCTION OF m-NITROACETOPHENONE

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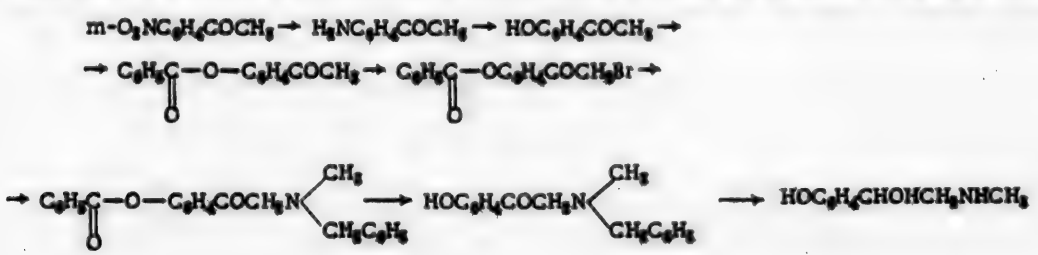
In order to synthesize m-aminophenyl-β-(methylamino)-ethanol (m-$NH_2C_6H_4CHOHCH_2NHCH_3$), which has not been described in the literature, we chose a procedure in which we first condensed m-nitro-ω-bromoacetophenone with benzylmethylamine and then reduced the resulting amino ketone. This procedure seemed to us to be convenient because of the availability of the initial substances: m-nitroacetophenone and m-nitro-ω-bromacetophenone. Our experiments on the condensation of m-nitro-ω-bromoacetophenone with benzylmethylamine showed that the reaction was concluded within 3 hours, the yield of the refined amino ketone hydrochloride reaching 68-70% of the theoretical.

The next stage, the catalytic hydrogenation of m-nitro-ω-(methylbenzylamino)-acetophenone, is more complicated than the hydrogenation of the analogous aryl (methylbenzylaminoalkyl) ketones that are not ring-substituted or whose rings contain hydroxyl groups, since in this case the molecule contains the readily reduced nitro group, in addition to the benzyl and carbonyl group. In the hydrogenation of m-nitro-(methylbenzylamino)-acetophenone with palladium black at atmospheric pressure and at 20-25° all the 5 moles of hydrogen required for the formation of m-aminophenyl-β-(methylamino)-ethanol were absorbed, though the reaction was clearly of a step-by-step nature: the first three moles of hydrogen were absorbed very quickly, after which the reaction slowed down somewhat, the last mole of hydrogen being absorbed extremely slowly. The quantity of hydrogen absorbed quickly (3 moles) seemed to show that the nitro group was first reduced, though the literature suggested [1] that this was followed by the reduction of the benzyl group, with the carbonyl group the last to react.

To test this hypothetical reaction sequence we ran experiments in which hydrogenation was broken off after only 3 moles of hydrogen had been absorbed and after 4 moles had been absorbed. The first reaction yielded m-amino-ω-(methylbenzylamino)-acetophenone dihydrochloride, the second yielding m-amino-ω-(methylamino)-acetophenone dihydrochloride; these findings corroborated our reasoning.

When m-nitro-ω-(methylbenzylamino)-acetophenone was hydrogenated (again at atmospheric pressure) with a Raney nickel catalyst, only the nitro group was reduced, the resultant m-amino-ω-(methylbenzylamino)-acetophenone hydrochloride being recovered as its acetyl derivative. As for the m-aminophenyl-β-(methylamino)-ethanol, it was rather difficult to secure its dihydrochloride in crystalline form, which is in conformity with the data in the literature on similar compounds. The substance was purified by repeated reprecipitation of its ester from alcoholic solutions, a colorless powder being formed after prolonged standing in a vacuum desiccator above P_2O_5; we were unable to determine the melting point of this powder owing to its extremely high hygroscopicity. The structure of m-aminophenyl-β-(methylamino)-ethanol was proved by diazotizing it and converting the diazo compound into an azo dye by coupling it with β-naphthol and by decomposing it with water into racemic m-hydroxyphenyl-β-methylaminoethanol (hydrochloride). Though the latter has been described in the literature, it was synthesized as follows for the sake of a complete comparison:



In carrying out these reactions, the new factor was the catalytic reduction of m-nitroacetophenone. The catalyst used was either palladium on charcoal or Raney nickel. The nickel catalyst is particularly useful for reactions involving large quantities. The method of catalytic reduction of m-nitroacetophenone possesses many advantages over the noncatalytic methods cited in the literature [2]. The m-aminoacetophenone produced by this method has a m.p. of 95-98° and is fully satisfactory for synthetic purposes; its yield was 95% of the theoretical.

Nor does the literature contain any description of the methods of synthesizing and the properties of some intermediate compounds of the foregoing set of reactions [m-benzoyl-hydroxyacetophenone, m-benzoyl-hydroxy-ω-bromoacetophenone, and m-benzoylhydroxy-ω-(methylbenzylamino)-acetophenone], so that we have cited them in the experimental section of this paper.

The m-hydroxyphenyl-β-(methylamino)-ethanol hydrochloride synthesized by the above method proved to be identical with the compound synthesized from m-aminophenyl-β-(methylamino)-ethanol by diazotizing it and decomposing the diazo compound.

EXPERIMENTAL

The initial substance, m-nitrobromoacetophenone, was prepared by brominating m-nitroacetophenone dissolved in chloroform [3]. The m-nitro-ω-benzylmethylaminoacetophenone hydrochloride was prepared as follows: 4 g of m-nitro-ω-bromoacetophenone and 24 ml of absolute benzene were placed in a three-necked flask fitted with a stirrer and a calcium chloride tube and chilled to 3-5°, after which 3.96 g of benzylmethylamine was added a drop at a time to the chilled mixture. The mixture was stirred for 4 hours, and then the precipitated benzylmethylamine hydrochloride was filtered out. The yield was 3.08 g; the yield should have been 3.28 g theoretically. The benzene was driven off from the filtrate in vacuo on a water bath at a bath temperature of 30-40°, the remaining reddish hyaline substance being dissolved in absolute ether. The ether solution was filtered, and an ether solution of hydrogen chloride was added to it from a buret, which caused a light-yellow, readily deliquescent precipitate to settle out. The substance had a m.p. of 171-177° with decomposition after filtration and washing with acetone. The yield was 3.6 g or a 68.7% yield. After recrystallization from a mixture of absolute ethyl alcohol and methanol (3:1), m-nitro-ω-benzylmethylaminoacetophenone hydrochloride fused at 178° with decomposition.

4.932 mg substance: 0.403 ml N_2 (26.5°, 729 mm). 5.076 mg substance: 0.400 ml N_2 (23.5°, 729.7 mm). Found %: N 8.93, 8.71. $C_{16}H_{16}O_3N_2 \cdot HCl$. Calculated %: N 8.73.

m-Aminophenyl-β-methylaminoethanol dihydrochloride. 1.2 g of $PdCl_2 \cdot 2H_2O$ was dissolved in 10 ml of distilled water containing 5-6 drops of concentrated hydrochloric acid, 20 ml of ethyl alcohol was added, and the whole was agitated in an atmosphere of hydrogen. 2 grams of m-nitro-ω-benzylmethylaminoacetophenone hydrochloride, dissolved in 20 ml of ethyl alcohol, was added to freshly reduced palladium black, and the whole was agitated in an atmosphere of hydrogen at 23-25°. 700 ml of hydrogen, or the quantity theoretically required, was absorbed during 1 hour 33 min. After the absorption of hydrogen stopped, the catalyst was filtered out and the solvent driven off in vacuo, leaving behind a slightly yellowish oil, which was dried in a vacuum desiccator above P_2O_5 for 8-10 hours to eliminate any vestiges of moisture. Adding ether to an alcoholic solution of the substance threw down a colorless amorphous precipitate, which was so hygroscopic as to render determination of its melting point impossible. The synthesized amino alcohol was reprecipitated several times from an alcoholic solution by ether and dried in a vacuum desiccator above P_2O_5, after which it was found to be a colorless powder that rapidly deliquesced and reddened when exposed to the air. The yield was 0.81 g, or 54%.

The m-aminophenylmethylaminoethanol dihydrochloride is freely soluble in water (without being hydrolyzed) and in absolute alcohol, its alcoholic solution exhibiting no change in color when it is stored in the dark for 2-3 weeks.

4.862 g substance: 3.93 ml 0.01 N H_2SO_4. Found %: N 11.32; $C_9H_{14}ON_2 \cdot 2HCl$. Calc.%: N 11.70.

Coupling with β-naphthol. 0.63 g of the oily substance secured by reducing m-nitrophenyl-ω-benzylmethylaminoacetophenone (cf. the preceding experiment) was diazotized without preliminary purification. The substance was dissolved in 12 ml of 7% hydrochloric acid and diazotized at −3° with a 0.5 N solution of sodium nitrite. During diazotization 5.47 ml of the 0.5 N sodium nitrite was absorbed, equivalent to 0.188 g (the theoretical quantity of sodium nitrite required for diazotization being 0.21 g). The solution

of the diazo compound was partially neutralized with soda and slowly poured into a chilled solution containing 0.35 g of β-naphthol*; a bright-red amorphous precipitate was thrown down; it was filtered out 3-4 hours later, washed with small amounts of cold water, and dried in a vacuum desiccator. The dry dye was triturated a few times in a mortar with ether to eliminate organic impurities, filtered, and dried.

4.906 mg substance: 0.513 ml N_2 (21°, 728 mm). 3.305 mg substance: 0.344 ml N_2 (22.5°, 735.5 mm). Found %: N 11.63, 11.64. $C_{19}H_{19}O_2N_3 \cdot HCl$. Calculated %: N 11.74.

Conversion of m-aminophenyl-β-(methylamino)-ethanol into m-hydroxyphenyl-β-(methylamino)-ethanol. 0.3 g of m-aminophenyl-β-methylaminoethanol hydrochloride (unrefined) was dissolved in 25 ml of 10% hydrochloric acid; the solution was chilled to 3° and diazotized with an 0.5 N solution of sodium nitrite while stirred (until iodized starch paper turned blue). Stirring was continued for another 10-15 minutes to complete diazotization, after which the solution was slowly heated to 80° on a water bath and kept at that temperature until no more nitrogen was evolved. The solution acquired a slightly pinkish color. The water was driven off in vacuo to dryness, absolute ethyl alcohol being added to the residue and the residue of insoluble sodium chloride filtered out. The alcohol was driven out of the filtrate in vacuo, and the residual mass was dried in a vacuum desiccator above P_2O_5. The resultant dark-brown, oily substance was dissolved in a small quantity of absolute ethyl alcohol, and absolute ether was added until the solution turned cloudy. After some time had elapsed, an oil separated from the solution; the solution was decanted from the oil into a clean flask, and ether was again added to this solution until it turned cloudy; some 40-50 minutes later pale-yellow crystals began to settle out. This yielded 0.09 g of a substance that had a m.p. of 131-136° (with decomposition). When absolute ether was added to the mother liquor, another 0.04 g of a more faintly colored substance with a m,p. of 136-139° (with decomposition) settled out.

The two substances were combined, and were purified by repeated reprecipitation from an alcoholic solution with ether, yielding a colorless crystalline substance with a m.p. of 139-141°. The mixed melting point of the substance thus synthesized with the m-hydroxyphenylmethylaminoethanol prepared by reducing m-hydroxy-ω-benzylmethylaminoacetophenone exhibited no depression.

8.035 mg substance: 3.74 ml 0.1 N H_2SO_4. Found %: N 6.52. $C_9H_{13}O_2N \cdot HCl$. Calculated %: N 6.87.

m-Amino-ω-benzylmethylaminoacetophenone dihydrochloride. 1 g of m-nitro-ω-benzylmethylaminoacetophenone was dissolved in 40 ml of methanol and agitated in hydrogen with palladium black, prepared by reducing 1 g of palladium chloride. Hydrogenation was broken off after 200 ml of hydrogen had been absorbed within 10 minutes, after which the reaction slowed down greatly (210 ml of hydrogen being required theoretically to reduce the nitro group). The catalyst was filtered out, the solvent was driven off in vacuo, and the residue was dried in a vacuum desiccator above P_2O_5. We were unable to crystallize the resultant light-brown hyaline mass The substance was purified by converting it into a base by adding an aqueous solution of ammonia until its reaction was strongly alkaline. The base was extracted with ether, the ether solution was dried with potash, and then an ether solution of hydrogen chloride was added from a buret a drop at a time until the reaction to Congo red was acid. The dihydrochloride settled out as a colorless flocculent precipitate that quickly deliquesced in air. The precipitate was washed a few times with absolute ether and dried in a vacuum desiccator over P_2O_5 The product was a colorless, extremely hygroscopic powder Its high hygroscopicity made it impossible to determine its melting point.

6.696 mg substance: 4.12 ml 0.1 N H_2SO_4. 8.087 mg substance: 4.79 ml 0.1 N H_2SO_4.
Found %: N 8.61, 8.29. $C_9H_{14}ON_2 \cdot 2HCl$. Calculated %: N 8.56.

m-Amino-ω-methylaminoacetophenone dihydrochloride. A solution of 2 g of m-nitro-ω-benzylmethylaminoacetophenone hydrochloride in 60 ml of ethyl alcohol was added to freshly reduced palladium black, prepared from 1.2 g of $PdCl_2 \cdot 2H_2O$, and the mixture was agitated in hydrogen until 500 ml of hydrogen was absorbed (the amount theoretically required to reduce the nitro group and split off the benzyl group), and then the reaction was broken off. The catalyst was filtered out, and the filtrate was evaporated in vacuo to dryness. The oily residue was dissolved in absolute ethyl alcohol and then rubbed with a glass rod, throwing down a colorless amorphous precipitate, which was filtered out and washed with alcohol. This yielded 0.55 g or 37% of the theoretical. The substance was purified by precipitation with acetone from a methanol solution. Decomposition temperature: 208°.

4.110 mg substance: 0.446 ml N_2 (28.5°, 731.3 mm). 5.902 mg substance: 7.024 mg AgCl. 5.868 mg substance: 6.985 mg AgCl.
Found %: N 11.79; Cl 29.44, 29.45. $C_9H_{12}ON_2 \cdot 2HCl$. Calculated %: N 11.81. Cl 29.94.

*) The coupling solution of β-naphthol was prepared by the method given by Fierz-David: 0.1 mole of β-naphthol, 15 ml of a 30% solution of NaOH, and 25 g of soda were dissolved in the necessary quantity of water.

m-Acetylamino-ω-benzylmethylaminoacetophenone hydrochloride. 0.5 g of m-nitro-ω-benzylmethylaminoacetophenone was dissolved in 20 ml of methanol, and the solution was agitated with 0.5 g of a Raney nickel catalyst in an atmosphere of hydrogen. 110 ml of hydrogen was absorbed in 6 hours at 16-18° (theoretically 105 ml of hydrogen was required to neutralize the nitro group) after which further absorption of hydrogen ceased. The substance secured after the catalyst had been filtered out and the solvent driven off in vacuo did not crystallize; it was heated on a water bath for 10-15 minutes with an excess of acetic anhydride, after which a small portion of the oily product was transferred to a watch glass and triturated with acetone, yielding crystals that were utilized as seeds. The crystallized mass was washed with acetone, yielding 0.3 g of a colorless substance that fused at 193-195° with decomposition. The m.p. of the substance was 206-207° after recrystallization from absolute ethyl alcohol; it was freely soluble in aqueous ethyl alcohol, but insoluble in acetone, ethyl acetate, or petroleum ether.

6.283 mg substance: 3.64 ml 0.01 N H_2SO_4. 3.345 mg substance: 1.94 ml 0.01 N H_2SO_4.
Found %: N 8.11, 8.12. $C_{18}H_{22}O_2N_2 \cdot HCl$. Calculated %: N 8.40.

Catalytic Reduction of m-Nitroacetophenone

a) Reducing m-nitroacetophenone with 10% palladium on charcoal. 1 g of m-nitroacetophenone was dissolved in 25 ml of ethyl acetate and then agitated in hydrogen with 0.1 g of the catalyst at room temperature (18-20°) and atmospheric pressure. During the course of 20 minutes 410 ml of hydrogen was absorbed (406 ml being called for theoretically). The catalyst was filtered out, and the solution was evaporated in vacuo, yielding m-aminoacetophenone as a crystalline precipitate with a m.p. of 89-91°. Recrystallization from water yielded 0.58 g of m-aminoacetophenone with a m.p. of 94.5-96°. The yield was 71%.

b) Reduction with Raney nickel. We ran numerous experiments in the course of our study of the optimum conditions for reducing m-nitroacetophenone with Raney nickel. The best conditions are described below. 20 g of m-nitroacetophenone was dissolved in 150 ml of ethyl acetate and then agitated with 10 g of the catalyst in hydrogen at 20-25°. The theoretical quantity of hydrogen (8140 ml) was absorbed within 90-120 minutes. After the catalyst had been filtered out and the solvent driven off in vacuo there was left behind in the flask an oily substance that quickly crystallized; m.p. 94-96°. This yielded 15.5 g of m-aminoacetophenone (94.7%).

Synthesis of m-hydroxyphenyl-β-(methylamino)-ethanol. m-Benzoylhydroxyacetophenone was prepared by reacting 5.5 g of m-hydroxyacetophenone* dissolved in 25 ml of pyridine with 1.5 g of benzoyl chloride. Recrystallization from petroleum ether yielded 8.4 g (86.6%) of colorless acicular crystals with a m.p. of 47-51°. The m.p. was raised to 52-53° after another recrystallization from a queous alcohol.

3.069 mg substance: 8.478 mg CO_2; 1.399 mg H_2O.
Found %: C 75.34; H 5.10. $C_{15}H_{12}O_3$. Calculated %: C 74.99; H 5.03.

m-Benzoylhydroxy-ω-bromoacetophenone.** We used 10 g of m-benzoylhydroxyacetophenone in 50 ml of chloroform and 7 g of bromine in 10 ml of chloroform. After the reaction was over and the solvent had been driven off, the residue was washed with small portions of ether and then recrystallized from alcohol. This yielded 10.8 g of a substance with a m.p. of 99-102°. The substance was fully stable toward ethyl alcohol, freely soluble in acetone and chloroform, and sparingly soluble in petroleum ether and benzene. A sample prepared for analysis had a m.p. of 105-106°.

0.2072 g substance: 0.1212 g AgBr. 0.2046 g substance: 0.1198 g AgBr.
Found %: Br 24.89, 24.96. $C_{15}H_{11}O_3Br$. Calculated %: Br 25.05.

m-Benzoylhydroxy-ω-benzylmethylaminoacetophenone hydrochloride. 4 g of m-benzoylhydroxy-ω-bromoacetophenone and 20 ml of absolute benzene were placed in a three-necked flask fitted with a stirrer and a calcium chloride tube, and 3.03 g of benzylmethylamine was added drop by drop to the suspension, which was thoroughly stirred and chilled externally with ice.

Stirring was continued for 3-4 hours, after which the precipitated benzylmethylamine hydrobromide was filtered out. The yield was 2.28 g, theory calling for 2.4 g. The filtrate was evaporated in vacuo to dryness, the residue being dissolved in absolute ether. The ether solution turned slightly cloudy; it was filtered through a pleated filter, and the chilled filtrate was stirred while an ether solution of hydrogen chloride was added from a

* m-Hydroxyacetophenone was prepared from m-aminoacetophenone by the Rupe and Majewski method [4].

** m-Benzoylhydroxy-ω-chloroacetophenone is employed as the initial substance in the patents.

buret until the reaction to Congo red was acid. The light-yellow amorphous precipitate of m-benzoylhydroxy-ω-benzylmethylaminoacetophenone that was thrown down was highly hygroscopic. The precipitate was transferred as quickly as possible to a filter together with the ether and washed several times with absolute ether, always leaving some ether in the funnel. The precipitate, moistened with ether, was dried in a vacuum desiccator. The yield was 3.88 g (78.3%). The substance was freely soluble in absolute ethyl alcohol, methanol, and acetone, and insoluble in ether. Its aqueous solution hydrolyzed readily. The unpurified m-benzoylhydroxy-ω-benzylmethylaminoacetophenone hydrochloride was then analyzed.

0.0403 g substance: 7.3 ml 0.015 N HCl. Found %: N 3.80. $C_{23}H_{22}O_3N \cdot HCl$. Calc.%: N 3.54.

m-Hydroxy-ω-benzylmethylaminoacetophenone hydrochloride. 4 g of m-benzoyl-hydroxy-ω-benzylmethylaminoacetophenone hydrochloride was refluxed on a water bath in a round-bottomed flask for 6 hours with 10 ml of a 10% alcoholic solution of hydrogen chloride. Driving off the solvent in vacuo left behind a dark, oily substance, which crystallized when chilled or when a small quantity of acetone was added. After recrystallization from absolute ethyl alcohol the m-hydroxy-ω-benzylmethylaminoacetophenone hydrochloride was a colorless crystalline substance with a m.p. of 200-201° (with decomposition). The yield was 2.2 g (75%). The substance was soluble in methanol, less so in ethyl alcohol; freely soluble in water, and insoluble in acetone; its aqueous solution was not hydrolyzed.

8.098 mg substance: 0.353 ml N_2 (21.5°, 737 mm). 7.578 mg substance: 0.322 ml N_2 (22.5°, 739.5 mm). 5.545 mg substance: 2.675 mg AgCl. 5.810 mg substance: 2.855 mg AgCl. Found %: N 4.90, 4.78; Cl 11.93, 12.20. $C_{16}H_{17}O_2N \cdot HCl$. Calculated %: N 4.80; Cl 12.18.

m-Hydroxyphenylmethylaminoethanol hydrochloride. 1.15 g of m-hydroxybenzylmethyl-aminoacetophenone hydrochloride was dissolved in 50 ml of ethyl alcohol, added to freshly reduced palladium black (prepared from 1 g of $PdCl_2 \cdot 2H_2O$), and agitated in hydrogen at 30°, 180 ml of hydrogen being absorbed within 20 minutes. After the catalyst had been filtered out and the solvent had been driven off in vacuo, the resultant oily substance was dried for 4-5 hours in a vacuum desiccator above P_2O_5. Subsequent trituration with 3 ml of absolute ethyl alcohol yielded a colorless crystalline precipitate. The yield was 0.45 g with a m.p. of 140-141°. The addition of absolute ether to the mother liquor yielded another 0.28 g with a m.p. of 138-141°. Recrystallization of the combined precipitates from alcohol yielded 0.67 g (84%) with a m.p. of 141-142°.

6.731 mg substance: 3.30 ml 0.01 N H_2SO_4. 6.758 mg substance: 3.34 ml 0.01 N H_2SO_4. Found %: N 6.86, 6.92. $C_9H_{13}O_2N \cdot HCl$. Calculated %: N 6.87.

SUMMARY

1. m-Aminophenyl-β-(methylamino)-ethanol has been synthesized; the structure of this compound was proved by converting it into the hydrochloride of the known m-hydroxyphenyl-β-(methylamino)-ethanol.

2. m-Hydroxyphenyl-β-(methylamino)-ethanol has been synthesized by the method proposed.

3. A method is given for synthesizing m-aminoacetophenone catalytically.

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THE MECHANISM OF THE WOHL REACTION FOR SYNTHESIZING PHENAZINE

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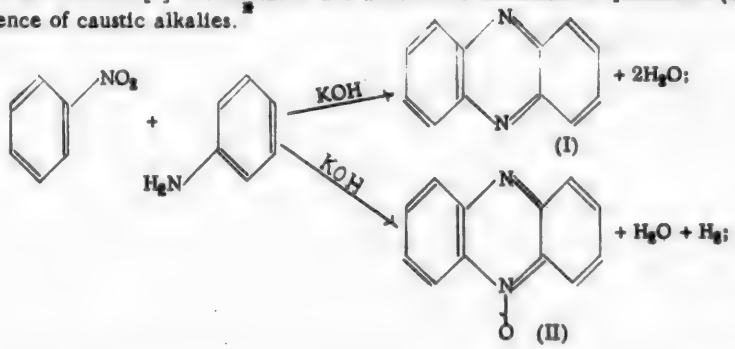
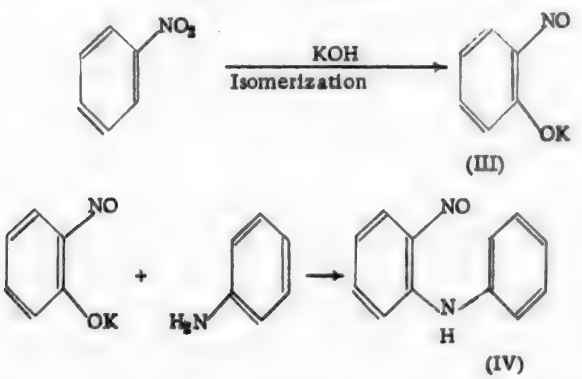
The occasion for our consideration of the Wohl reaction has been an interest in phenazine and some of its derivatives as raw material for the synthesis of microorganism pigments: pyocyanin [1], iodinin [2], and chlororaphin [3].

In the Wohl reaction [4] nitrobenzene and aniline are condensed to phenazine (I) or phenazine oxide (II) in the presence of caustic alkalies.*

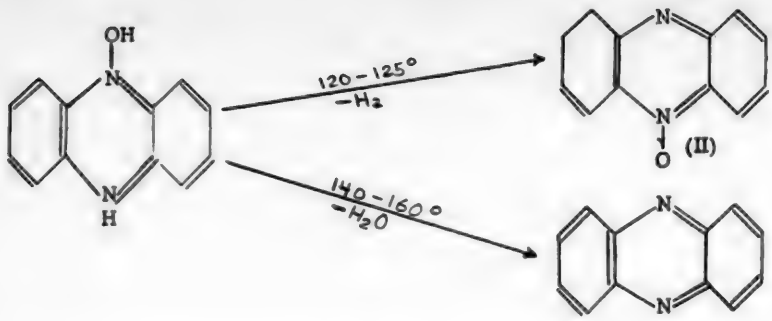


Wohl assumed that nitrobenzene was isomerized in the presence of a caustic alkali into the unstable o-nitrosophenol (III) which has not been isolated up to the present time (cf. Diagram I), the o-nitrosophenol reacting with aniline to yield o-nitrosodiphenylamine (IV), which is converted into phenazine oxide (II) when the reaction is carried out at 120-125° and into phenazine (I) at a higher temperature (140-160°). The yield of (I) + (II) was about 15% .

Diagram I



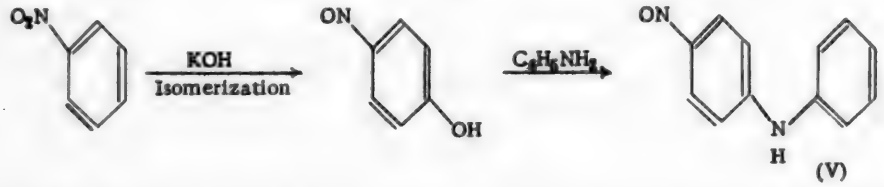
* Analogously, derivatives of nitrobenzene and aniline yield substitution derivatives of phenazine.



(1)

Wohl cited the following findings in support of this reaction sequence.

When he treated a water-alcohol solution of the tarry precipitate secured in the reaction with carbon dioxide, he succeeded in isolating p-nitrosophenylamine (V) as a by-product alongside the phenazine. Wohl considered the formation of this compound to result from the reaction of the p-nitrosophenol with aniline [5]:

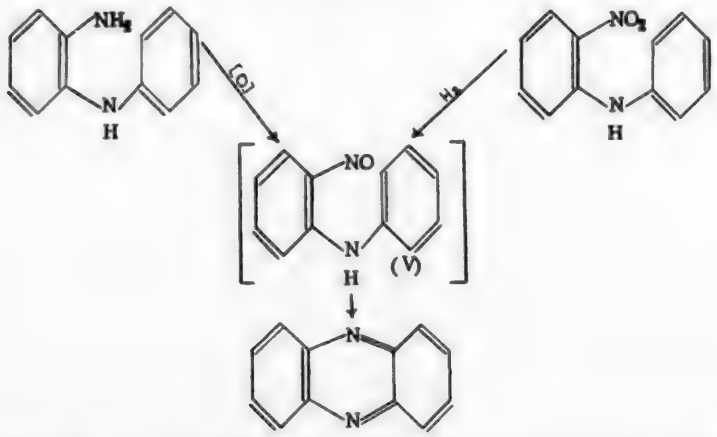


(V)

It was this fact that led Wohl to believe that o-nitrosodiphenylamine (IV) was the intermediate product in the synthesis of phenazine.

This supposition—that o-nitrosodiphenylamine is formed as an intermediate product—seems probable, inasmuch as Wohl succeeded in recovering p-nitrosodiphenylamine. Moreover, the synthesis of phenazine by the other known methods, such as oxidizing o-aminodiphenylamine [6], reducing o-nitrodiphenylamine [7], or, finally, fusing a mixture of o-nitrodiphenylamine and o-aminodiphenylamine with sodium acetate [8] (cf. Diagram 2), apparently also involves the formation of o-nitrosodiphenylamine as an intermediate product, though it cannot be isolated because of its instability.

Diagram 2



In assuming that o-nitrosodiphenylamine is formed as an intermediate product, however, Wohl presupposed that the formation of this compound was an indispensable prerequisite for the isomerization of nitrobenzene to o-nitrosophenol (cf. Diagram 1). Wohl regarded the fact that the action of potassium hydroxide on nitrobenzene at 60-70° produces a 33% yield of potassium o-nitrophenolate plus a small amount of potassium

p-nitrophenolate as a proof of such isomerization. (He believed that the nitro compounds were secured by oxidation of the nitroso compounds formed in the initial reaction stage by the excess nitrobenzene).

This supposition cannot be regarded as correct today, for we have learned that the reaction in which nitrophenols are formed from nitrobenzene by fusion with an alkali must be considered a direct hydroxylation of the nitrobenzene, in which there is an "illegal" orientation to the ortho position (see below for substitution reactions of the second kind [5].) In the light of this, Wohl's whole reaction sequence falls to the ground.

To discover the actual course of the reaction, we felt it was first necessary to make an experimental check of whether potassium o-nitrosophenolate can take part in the Wohl reaction.

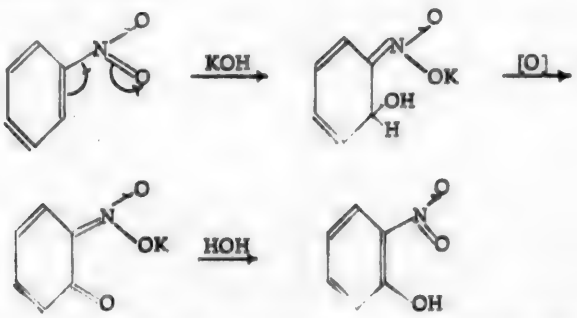
Orthonitrosophenol is a highly unstable product, existing only in solution. We have shown that o-nitrosophenol in solution, prepared as specified by Baudisch [9], exhibits no tendency to enter into a condensation reaction with aniline, whereas the stable naphthalene analog of o-nitrosophenol, 1-nitroso-2-naphthol, does not yield even a trace of benzophenazine when reacted with aniline under the conditions specified by Wohl (140-160°, KOH). If we assume that 1-nitroso-2-naphthol exists primarily as the monooxime of orthoquinone, then condensation with aniline ought to be all the smoother. Moreover, we have shown that phenazine can be synthesized from nitrobenzene and aniline without employing a caustic alkali, provided sodium anilide is used in the reaction instead of aniline and the caustic alkali and the reaction is carried out in xylene.

All this indicates that orthonitrosophenol can hardly be an intermediate product in the Wohl reaction.

Azobenzene is secured as a by-product in the Wohl reaction. The formation of this compound cannot be explained by Wohl's reactions. Nor can azobenzene be looked upon as an intermediate product capable of closing the phenazine ring, since we have found that heating azobenzene with potassium hydroxide and nitrobenzene in the Wohl reaction conditions does not yield phenazine.

Analyzing all these findings we concluded that the reaction of nitrobenzene with aniline in the presence of caustic alkalies (A. Wohl) or of sodium amide (Z. V. Pushkareva, Agibalova [10]) must be regarded as a typical instance of a substitution of the second kind, i.e., an inverted orientation of the nitro group when acted upon by nucleophilic reagents (caustic alkali, sodium amide). These reactions result in the formation of phenazine or of phenazine oxide (cf. Diagram 3).

In these reactions the $(OH)^-$ and $(NH_2)^-$ anions attack those carbon atoms in which the electron density is a minimum owing to the polarization of the nitrobenzene molecule, i.e., in the ortho or para positions. The following reactions are instances of this sort:



1) The above-mentioned oxidation of nitrobenzene to orthonitrophenol when nitrobenzene is fused with solid potassium hydroxide [5] in the air:

2) The amination of 1,3-dinitrobenzene to 1,3,4-dinitroaniline [11].

3) The synthesis of p-nitrophenylcarbazole from nitrobenzene and carbazolesodium [2].

4) The reaction of nitrobenzene with piperidinesodium, yielding p-nitro-N-phenylpiperidine [3].

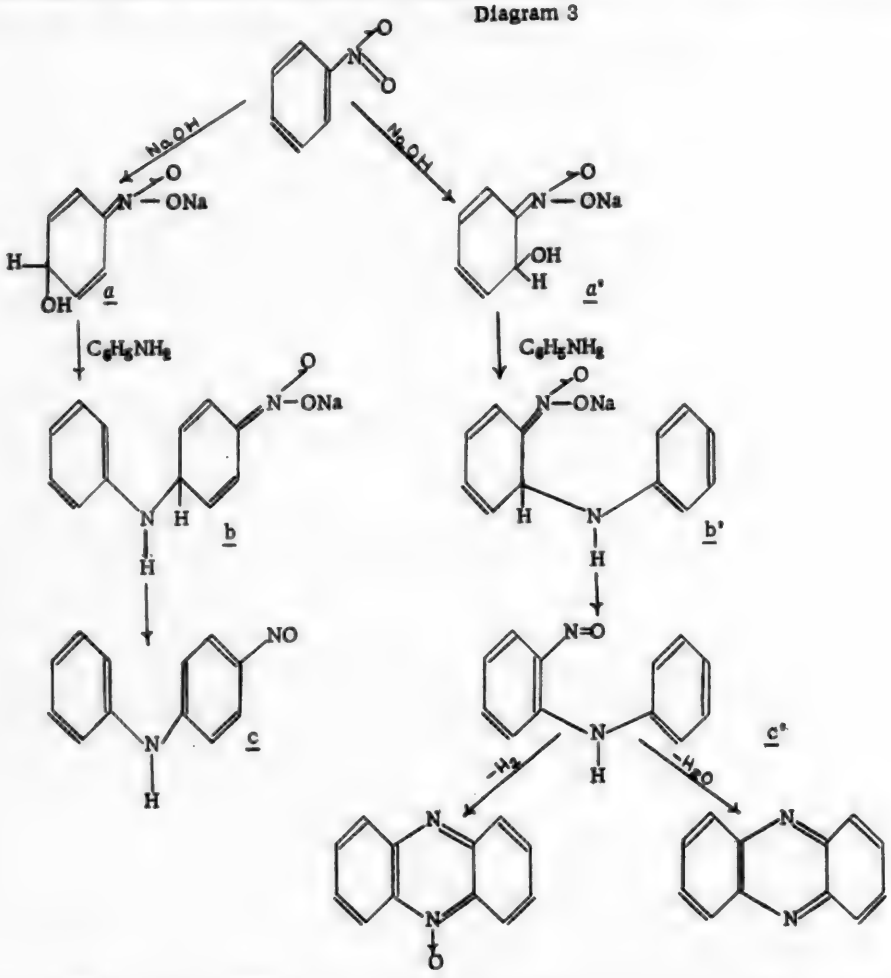
The amination and hydroxylation of pyridine and quinoline at the α- and γ-positions to the heterocyclic nitrogen [14] instead of the usual substitution at the β- position are other instances of this type of reaction.*

* The nitrogen in the pyridine and quinoline rings plays the same part in orientation as the nitro group in nitrobenzene.

Other examples might be cited of "illegal" orientation, such as the hydroxylation of resorcinol by an alkali [15], the hydroxylation of 1- or 2-hydroxyanthraquinone [16], the hydroxylation of β-anthraquinonesulfonic acid to alizarin when fused together with an alkali, and the condensation of benzenanthrone in fusion with an alkali [17].

In the light of the foregoing, the condensation of nitrobenzene with aniline in the presence of a caustic alkali must be looked upon as follows (cf. Diagrams 3 and 4).

Diagram 3



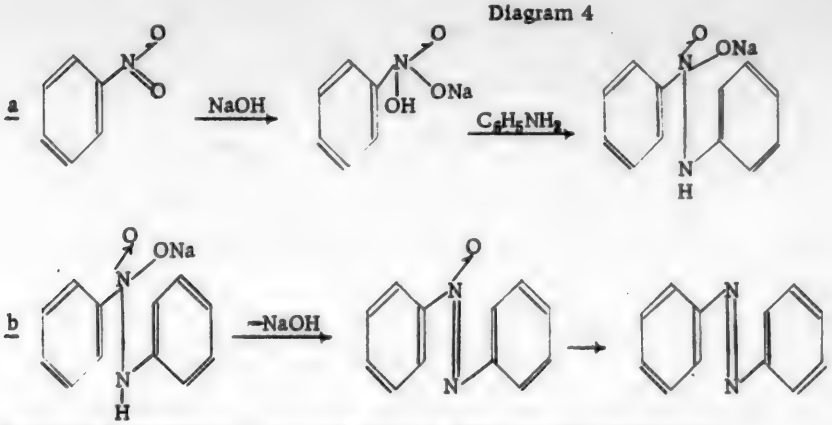
In Diagram 3 the $(OH)^-$ anion is added to the polarized nitrobenzene molecule at the para and ortho positions at the instant of chemical reaction (experiment indicating that the ortho reaction predominates). The resultant compounds, a and a', have a hydroxyl group attached to a saturated carbon atom and are quinols, which react readily with aniline.

The quinanilides b and b' are converted into stable benzene compounds by the splitting off of a molecule of sodium hydroxide (c and c'). As for the side reaction in which azobenzene is formed, this may be represented as involving the addition of a molecule of sodium hydroxide at the nitro group, with the resultant addition product reacting with aniline (cf. Diagram 4, a and b).

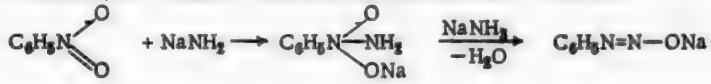
First azoxybenzene is formed, turning into azobenzene under the reaction conditions. (In a special test we have shown that azoxybenzene is converted into azobenzene at 140° when aniline and a caustic alkali are present, i.e., under the conditions of the Wohl reaction).

The addition of sodium amide to the nitrogroup of nitrobenzene has been described already in the literature [18]. When sodium amide is reacted with nitrobenzene for a long time in the cold, sodium

Diagram 4

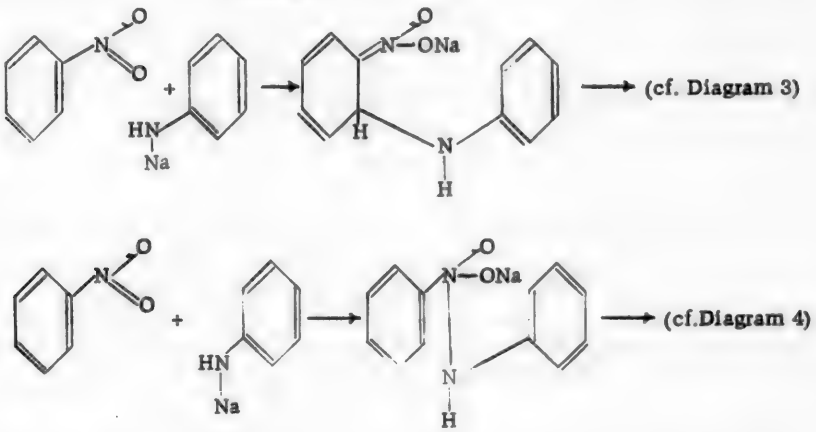


diazotate is formed (via a stage in which an addition product is formed):



A particularly striking example of a reaction involving inverted orientation is the formation of phenazine when nitrobenzene is reacted with sodium anilide. By so doing we have managed to secure 30-35% yields of phenazine, based on the reacted nitrobenzene. This reaction may be represented as follows:

Diagram 5



It is not impossible that when a caustic alkali or sodium amide is employed, the Wohl reaction takes place only after sodium anilide has been formed, the latter then entering into the reaction as shown in Diagram 5.

EXPERIMENTAL

Reaction of orthonitrosophenol with aniline. The orthonitrosophenol solution was prepared as specified by Baudisch [9]. 0.5 g of orthonitrophenol was heated in a small quantity of glacial acetic acid until it dissolved, the acetic acid solution being chilled and 1-2 ml of water being added, causing the orthonitrophenol to settle out in a finely crystalline state. Petroleum ether was added to the suspension of orthonitrophenol in acetic acid, and 0.3 g of zinc dust was added to the vigorously shaken mixture. The acetic acid solution turned red, the petroleum ether turning yellow at first, and then green, due to the resultant orthonitrosophenol.*

* The formation of the copper salt of orthnonitrosophenol was evidence of the formation of the latter compound. When a petroleum ether solution of orthonitrosophenol was agitated with a highly diluted solution of copper sulfate, the latter turned an intense red, due to the formation of a copper salt of orthonitrosophenol.

The solution of orthonitrosophenol in petroleum ether was mixed with an excess of aniline, and the reaction mass was allowed to stand for 3 days at room temperature. The top layer of petroleum ether, which was an intense green at first, gradually turned a faint yellow, while the bottom layer of aniline changed from yellow to a cherry-red (in the proportions used aniline is insoluble in petroleum ether). After standing for three days, the reaction mass was steam-distilled; the distillate contained an extremely minute quantity of oil, which was separated from the water. The aniline in the oil dissolved when the latter was agitated with a dilute solution of hydrochloric acid. The insoluble yellow substance was washed with dilute hydrochloric acid and with water and then dried in a desiccator. The m.p. of the yellow substance was 43°. The substance was identical with the initial orthonitrosophenol. No phenazine was found in the residue left after the steam distillation.

Heating a solution of the orthonitrosophenol in ligroin with aniline on a boiling water bath or with aniline and potassium hydroxide in a Wohl reaction yielded neither phenazine nor phenazine oxide.

Reaction of 1-nitroso-2-naphthol with aniline under Wohl reaction conditions. A mixture of 17.3 g of 1-nitroso-2-naphthol, 9.3 g of aniline, and 40 g of finely pulverized anhydrous potassium hydroxide was heated to 140-160° for 16 hours, in strict compliance with the conditions specified for the Wohl reaction. Steam was passed through the dark tarry mass produced as a result of the reaction. The steam-distillation residue was washed with water, much of the reaction mass dissolving. The residual dark black tar was extracted with 20% hydrochloric acid. No benzophenazine could be recovered from the hydrochloric acid solution by adding ammonia to it, which is evidence that orthonitrosonaphthol does not react with aniline under Wohl reaction conditions to yield benzophenazine.

Synthesis of Phenazine by Reacting Nitrobenzene with Sodium Amide.

Synthesis of sodium anilide by the Chichibabin method [17]. 7.8 grams of finely pulverized sodium amide was added as fast as possible to 18.6 g of freshly distilled aniline. The reaction mass grew very hot, and ammonia was liberated, the color gradually changing from red to green, and then to dark-brown. As soon as the evolution of heat by the reaction mass ceased, the mass was placed in an oil bath at 120° and kept at that temperature for 20 minutes, after which the temperature was raised to 160.170°. After being heated to 160-170° for 5 minutes, the reaction mass was cooled to 100°, and 40 ml of anhydrous xylene was added to it (xylene does not dissolve the solid reaction product).

Synthesis of phenazine. The resultant sodium anilide was heated to 125°, and 24.6 g of nitrobenzene was slowly added to it from a dropping funnel. If the reaction did not set in, the oil-bath temperature was raised to 135-140° (but no higher). As soon as the reaction began, heating was stopped, the subsequent course of the reaction being controlled by regulating the rate at which the nitrobenzene was added. After all the nitrobenzene had been added, the thick, dark mass was heated to 140-145° (temperature of the oil bath) for 10 hours. After these 10 hours of heating, the xylene, the unreacted initial products—nitrobenzene and aniline, and the reaction by-product—azobenzene were driven off with steam. The liquid resinous mass left after the steam distillation, which solidified upon cooling, contained phenazine.

The resin was separated from the aqueous solution and extracted repeatedly by heating it with small portions of 20% hydrochloric acid. 2-3 ml of concentrated nitric acid were added to the dark hydrochloric acid solution, and the whole was brought to a boil. A resin floated to the top; it was filtered out after the solution had cooled.

The transparent orange-red hydrochloric-acid solution was neutralized with ammonia, throwing down a dark-yellow phenazine precipitate. The resultant phenazine was purified by reprecipitating it once or twice with ammonia from a solution in 20% hydrochloric acid. The phenazine yield was 30-32%, based on the reacted nitrobenzene; m.p. 168-169°. Recrystallization from 10 times its weight of alcohol yielded the characteristic shining yellow needles with a m.p. of 170-171°, exhibiting no depression when mixed with phenazine synthesized by a different method.

SUMMARY

1. It has been shown that the synthesis of phenazine in the Wohl reaction from nitrobenzene and aniline with an alkali present is an instance of the inverted orientation of the nitro group when acted upon by nucleophilic reagents (KOH, $NaNH_2$; cf. Diagram 3).

2. In conformity with this reaction pattern, phenazine has been synthesized by condensing nitrobenzene with another nucleophilic reagent—sodium anilide (cf. Diagram 5).

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XXXV. THE CONVERSION OF BUTYROLACTONE INTO THIOPHANONE-2, PYRROLIDONE-2, and 1-PHENYLPYRROLIDONE-2

Yu.K. Yuryev, E.G. Vendelshtein, and L.A. Zinovyeva

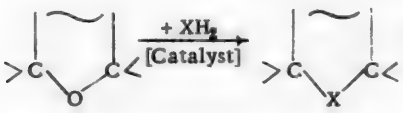
The conditions governing the substitution of an imino group for the bridge oxygen on the lactones of γ- and δ-hydroxy acids vary with the nature of the lactone. The conversion of phenolphthalein into imidophenolphthalein when it is allowed to stand with aqueous ammonia at room temperature [1] and the conversion of phthalide into phthalimidine [2] when ammonia is passed through phthalide at 290° are the extremes in the conditions governing the course of this side reaction.

H. Meyer [3] endeavored to deduce definite rules from the behavior of various γ- and δ-lactones when acted upon by ammonia and concluded that the decisive role is played by the nature of the hydroxyl group in the hydroxy acid yielding the given lactone. This led him to the following conclusions:

1. The reaction of γ- and δ-lactones with ammonia either does not take place at all or results in the formation of a more or less unstable amide of the hydroxy acid when the hydroxyl group is a primary group or a saturated secondary group or is a phenolic one: butyrolactone, γ-valerolactone, and γ-caprolactone could not be converted into the respective lactams, thus supporting the rule, though phthalide was converted into a lactam and, hence, constituted an exception to the rule.

2. γ- and δ-lactones react with ammonia to form imides—lactams of the γ- and δ-amino acids—when the hydroxyl group is a tertiary or a secondary unsaturated one (>C=CHOH): triphenylcrotolactone [4], phthalylacetic acid [5], and phenolphthalein [1] are representatives of compounds of this type.

The catalytic conversions of the original rings of the five-membered and six-membered oxygen-containing heterocyclic compounds into heterocyclic compounds containing nitrogen [6], sulfur [7], and selenium [8] are the natural completion of many years of research on the substitution of an imino group for the ring oxygen in cyclic anhydrides, in γ-pyrone, and in its derivatives. All these reactions must now be regarded as special instances of a reaction involving the replacement of ring oxygen by another hetero atom, which is quite generally applicable to all heterocyclic systems that contain oxygen and takes place under suitable conditions when reagents interact with the active hydrogen atoms:



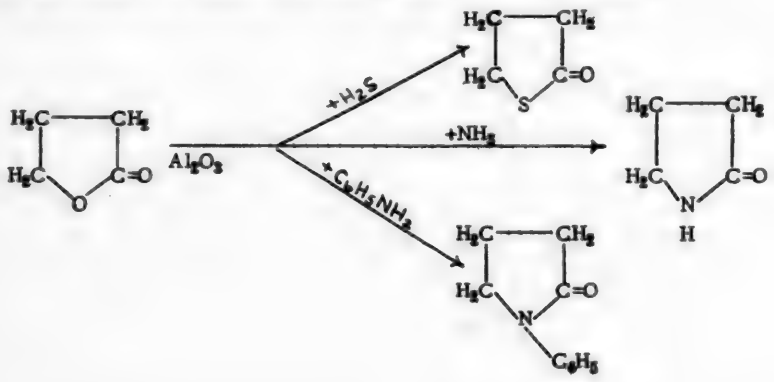
$+ H_2O$ (X = NH; NAlk; NAr, NPy; S; Se)

Hence, H. Meyer's rule has lost all significance, and, now that furan, the most stable of the oxygen-containing heterocyclic compounds, has been converted into pyrrole by the action of ammonia upon it in the presence of alumina at 450° [6], it is safe to say that the ring oxygen in butyrolactone and γ-valerolactone must be replaced by an imino group under conditions that are milder than those governing the conversion of furan but much more severe than those governing the conversion of other lactones, such as phthalide. The influence of the oxygen atom linked to the α-carbon atom in the ring makes the bond of the ring oxygen in butyrolactone weaker than it is in furan or furanidine, but stronger than in cyclic anhydrides or in substituted lactones, such as triphenylcrotolactone. That is why it is only by heating to 280° with liquid ammonia at considerable pressure that pyrrolidone-2 could be prepared from butyrolactone or 5-methylpyrrolidine-2 from γ-valerolactone [9].*

* The authors do not state the pyrrolidone yields.

Butyrolactone must likewise suffer the catalytic substitution of sulfur or of an imino group for its ring oxygen, though at much lower temperatures than in the case of furan and furanidine. Lowering the reaction temperature could not, however, eliminate an appreciable decomposition of butyrolactone, due to its instability.

In the present research butyrolactone has been converted into thiophanone-2 (tetrahydro-α-thienone) by the action of hydrogen sulfide, into pyrrolidone-2 by the action of ammonia, and into 1-phenylpyrrolidone-2 by the action of aniline—all at 350° in the presence of alumina:



EXPERIMENTAL

Conversion of Butyrolactone into Thiophanone-2 (Tetrahydro-α-thienone; Butyrothiolactone)

300°. 8 g of butyrolactone (b.p. 83-85° at 5 mm); n_D^{20} 1.4369; d_4^{20} 1.1288) was passed through a tube containing alumina at the rate of 12 drops per minute in a current of hydrogen sulfide. The catalyzate was extracted with ether. After the ether had been driven off from the ether extract of the catalyzate (which had been dried with calcium chloride), the reaction product was distilled in vacuo, yielding the following fractions: I) b.p. 109.5-110° (51 mm)—2.5 g; and II) b.p. 110-111° (51 mm)—0.3 g. Fraction I was thiophanone-2 (30% of the theoretical yield).

325°. 8 g of butyrolactone yielded 3.5 g of thiophanone-2 (38% of the theoretical yield).

350°. 8 g of butyrolactone yielded 6 g of thiophanone-2 (72% of the theoretical yield).

375°. 8 g of butyrolactone yielded 2.8 g of thiophanone-2 (30% of the theoretical yield).

The thiophanone-2 secured in all the tests was combined and redistilled in vacuo (from a flask with a dephlegmator); its constants then were:

B.p. 110.5 (52 mm); n_D^{20} 1.5189; d_4^{20} 1.1635; MR_D 26.39; calculated 26.45.

Melting point of the compound with corrosive sublimate (from alcohol); 118.5°. Found %: C 46.92, 46.98; H 5.89, 5.86; S 31.24, 31.30. C_4H_6OS. Calculated %: C 47.05; H 5.92; S 31.39.

Thiophanone-2 is a colorless liquid with the characteristic odor of garlic. It is freely soluble in alcohol and in ether, though insoluble in water.

Reduction of thiophanone-2 to thiophane. 5.3 g of thiophanone-2 was reduced by boiling for five hours with 16 g of zinc amalgam and 32 ml of dilute (1:1) hydrochloric acid, with 5 ml of hydrochloric acid (sp.gr. 1.16) added every hour. Then the reaction product was distilled with steam, and the resultant distillate extracted with ether. The ether extract was dried with anhydrous sodium sulfate, the ether driven off, and the residue distilled, yielding 0.8 g of a fraction with a b.p. of 116-122° (757 mm) and n_D^{20} 1.5021, which produced a crystalline compound with $HgCl_2$, whose m.p. was 125° after recrystallization from alcohol. The mixed melting point with a compound of thiophane with mercuric chloride exhibited no depression: m.p. 125°. Hence, the 116-122° fraction was thiophane (tetrahydrothiophene) produced by the reduction of thiophanone-2.

Figures in the literature for thiophane: Yu.K. Yuryev [10]: b.p. 119.8-120° (760 mm); n_D^{20} 1.5052; d_4^{20} 0.9960; m.p. of the compound with mercuric chloride: 124.5-125°.

Conversion of Butyrolactone to Pyrrolidone-2 and 1-Phenylpyrrolidone-2

1) 21 g of butyrolactone was passed over alumina (in 7-gram batches) in a current of ammonia at 350°. The ether extract of the catalyzate was dried with anhydrous sodium sulfate, the ether was driven off, and the residue was distilled in vacuo. Redistillation of the reaction product yielded the following fractions: I) b.p. 95-102°—0.2 g; II) b.p. 102-104° (5 mm)—3.2 g; and III) b.p. 104-110°—0.5 g.

Fraction II was pyrrolidone-2 (15.5% of the theoretical yield).

B.p. 102-104° (5 mm); n_D^{30} 1.4806; d_4^{30} 1.106; b.p. 23-24°. MK_D 21.88; calculated 22.23.
Found %: N 16.56. C_4H_7ON. Calculated %: N 16.44.

Figures in the literature for pyrrolidone-2: Gabriel [11]: b.p. 245°; m.p. 25-28°; Tafel and Stern [12]: b.p. 205.5° (742 mm); m.p. 24.6°; d_4^{30} 1.110 [12]: Späth and Lintner [9]: b.p. 100-105° (1 mm); m.p. 23-24°.

2) A mixture of 7 g of butyrolactone and 20 g of aniline was passed over alumina in a current of nitrogen at 350°. An ether extract of the catalyzate was dried the ether driven off, and the residue distilled in vacuum, repeated redistillation of the reaction product (after the unchanged aniline had been eliminated) yielding the following fractions: I) b.p. 140-150° (5 mm)—3 g; II) b.p. 150-155° (5 mm)—2.1 g; and III) b.p. 155-160° (5 mm)—1.8 g.

Fractions II and III crystallized; crystals settled out of Fraction I upon cooling.

The colorless crystals of 1-phenylpyrrolidone-2 fused at 66-67°. The yield was 4.3 g (32% of the theoretical).

Found %: N 8.78. $C_{10}H_{11}ON$. Calculated %: N 8.69.
Figures in the literature for 1-phenylpyrrolidone-2: Baille and Tafel [14]: m.p. 64-68°; b.p. 130-140° (1 mm); Späth and Lintner [9]: m.p. 65-67°.

SUMMARY

The catalytic conversion of butyrolactone into thiophanone-2, pyrrolidone-2, and 1-phenylpyrrolidone-2, effected in the present research, takes place at lower temperatures, though with lower yields, than in the case of furanidine (tetrahydrofuran), owing to the weakening of the butyrolactone ring by the presence of oxygen at the α-carbon atom of the ring.

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XXXVI. THE CONVERSION OF α,β'-DIMETHYLFURAN AND OF α,β'-DIMETHYLFURANIDINE INTO THE CORRESPONDING NITROGEN- AND SULFUR-CONTAINING HETEROCYCLIC COMPOUNDS

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In the catalytic conversion of homologs of furanidine (tetrahydrofuran) into the corresponding homologs of pyrrolidine and thiophane the yields of the latter regularly vary with the size of the alkyl radical and its position in the ring.

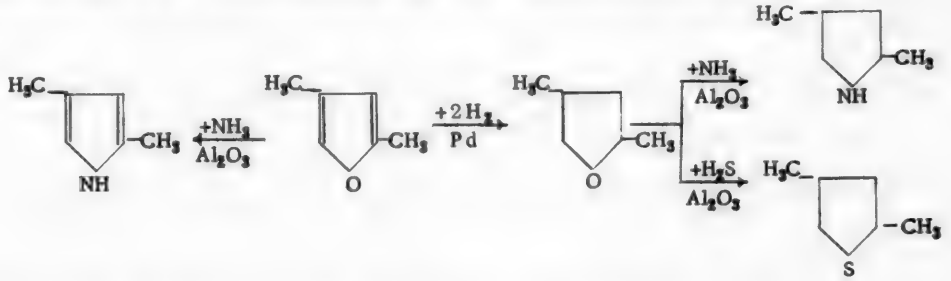
Alkyl radicals located at the α-position weaken the stability of the γ-oxide ring, causing an appreciable drop in the yield of α-alkylpyrrolidines and thiophanes, the magnitude of this effect depending upon the complexity of the alkyl radical. Hence, the reaction is carried out at a lower temperature than that which is best for converting the furanidine, in order to hold down the decomposition of the substance and secure better yields.

In synthesizing α-alkylpyrrolidines at 400°, the yields of α-methyl-[1], α,α'-dimethyl- [2], and α-ethylpyrrolidine [3] were 27.5%, 17.5%, and 9%, respectively, while the yield of pyrrolidine was 46.5% [4]. At 350°, the yield of α-propyl- and α-butylpyrrolidine was 10% [5], whereas the yield of pyrrolidine itself was 30.5% [4]. In synthesizing the α-alkylthiophanes at 350°, the yields of α-methyl- [6], α,α'-dimethyl- [2], α-ethyl-, α-propyl-, and α-butylthiophane [6] were 65%, 43%, 71%, 63% and 60%, respectively, the thiophane yield being 85%, and 90.5%at 400° [7].

When the alkyl radical is located at the β-position of the furanidine ring, the yield of the β-alkylpyrrolidine depends principally upon the size of the radical, the yields of pyrrolidine [4] and β-methylpyrrolidine [5] being 30% at 350°, while the yield of β-butylpyrrolidine was only 12% [5]. The yields of β-methyl, β-ethyl-, β-propyl-, and β-butylthiophane [6] were 81%, 80%, 72%, and 79%, respectively, when the β-alkylthiophanes were synthesized at 350°, i.e., almost the same as the thiophane yield (85%). Hence, the presence of an alkyl radical at the β- position does not affect the stability of the furanidine ring in this reaction.

When homologs of furan are converted into the corresponding homologs of pyrrole and thiophene, the yields of these latter products are likewise reduced, the magnitude of the reduction increasing with increasing size of the alkyl radical located at the α-position of the furan ring.

In the present research we have effected the catalytic conversion of α,β'-dimethylfuran into α,β'-dimethylpyrrole and of α,β'-dimethylfuranidine into α,β'-dimethylpyrrolidine and α,β'-dimethylthiophane.



The yields of these compounds were higher than those of α,α'-dimethylpyrrole (16%), α,α'-dimethylpyrrolidine (17.5%), or α,α'-dimethylthiophane (43%); hence, the yields of the products of this reaction were governed principally by the methyl group located at the α-position of the oxygen-containing heterocyclic ring.

EXPERIMENTAL

α,β'-Dimethylfuran was prepared by using sulfuric acid to condense acetoacetic ester [8], followed by reacting bromine water with the resultant isodehydracetic acid [9] and decarbonizing the resultant α,β'-dimethylfuran-β'-carboxylic acid [10], as well as by a new method we have developed, the pyrolysis of a sultone: the cyclic sulfoether of mesityl oxide [11].

The constants of α,β'-dimethylfuran were as follows after distillation over sodium:

B.p. 93-93.1° (742 mm); n_D^{20} 1.4387; d_4^{20} 0.8996. MR_D 28.08. C_6H_8O F 2. Calculated MR_D 28.42.

The melting point of the compound with $HgCl_2$ was 111°.

The figures given in the literature for α,β'-dimethylfuran are: Yu. K. Yuryev, G. Ya. Kondratyeva, and S.N. Petrov [11]: b.p. 93-94° (760 mm); n_D^{20} 1.4371; d_4^{20} 0.8993. Gilman and Burtner [12]: m.p. of the compound with $HgCl_2$: 112°.

The α,β'-Dimethylfuranidine (2,4-dimethylfuranidine; 2,4-dimethyltetrahydrofuran) was prepared by hydrogenating α, β'-dimethylfuran catalytically. 40 grams of α, β'-dimethylfuran was passed over palladinized asbestos at 150-155° in a current of hydrogen. The resultant catalyzate was dried with calcium chloride and distilled above sodium in a flask fitted with a tall, highly efficient dephlegmator. The α, β'-dimethylfuranidine's constants were as follows after double distillation:

B.p. 97.5-97.7° (759 mm); n_D^{20} 1.4100; d_4^{20} 0.8433. MR_D 29.57: Calculated MR_D 29.35.

4.350 mg substance: 11.440 mg CO_2; 4.510 mg H_2O. 6.925 mg substance: 18.230 mg CO_2; 7.280 mg H_2O. Found %: C 71.77, 71.84. H 11.61, 11.76. $C_6H_{12}O$. Calculated %: C 71.95; H 12.08.

The yield was 30 g (72% of the theoretical). α,β'-Dimethylfuranidine is not described in the literature.

Conversion of α,β'-dimethylfuran into α,β'-dimethylpyrrole. 9.6 g of α,β'-dimethylfuran was passed over activated alumina at 330° in a current of ammonia at the rate of 5-6 drops per minute. The catalyzate was saturated with sodium hydroxide and extracted with ether. The ether was driven off from the dried ether extract, and the reaction product double-distilled, yielding α, β'-dimethylpyrrole, the constants of which were as follows:

B.p. 165-166° (758 mm); n_D^{20} 1.5048; d_4^{20} 0.9236. MR_D 30.54. C_6H_9N F 2. Calculated MR_D 30.38.

Picrate melting point (from alcohol) 92.5-93°.

6.250 mg substance: 0.793 ml N_2 (23°, 752 mm). Found %: N 14.48. C_6H_9N. Calculated %: N 14.72.

Yield: 2.4 g (25% of the theoretical).

The figures given in the literature for α, β'- dimethylpyrrole are: Knorr [13]: b.p. 165° (743 mm); Piloty et al [14]: b.p. 162-164° (720 mm); picrate melting point: 92-93°.

Conversion of α,β'-dimethylfuranidine into α, β'-dimethylpyrrolidine. 11.5 g of α, β'-dimethylfuranidine was passed over activated alumina at 300° in a current of ammonia at a rate of 5-6 drops per minute. After the catalyzate had been processed as specified above, the reaction product was distilled from a flask fitted with a dephlegmator.

The constants of the α, β'-dimethylpyrrolidine were as follows after redistillation:

B.p. 116-117° (761 mm); n_D^{20} 1.4347 d_4^{20} 0.8351. MR_D 30.98. Calculated 31.31.

Picrate melting point (from alcohol): 116-116.5°,

6.538 mg substance: 0.806 ml N_2 (22°, 756 mm). Found %: N 14.19. $C_6H_{13}N$. Calculated %: N 14.12.

Yield 4.7 g (41% of the theoretical).

The figures given in the literature for α,β'-dimethylpyrrolidine are: Knorr [13]: b.p. 115-117° (753 mm); n_D^{20} 1.4325; d_4^{20} 0.8297; picrate melting point: 116-117°.

Conversion of α,β'-dimethylfuranidine into α,β'-dimethylthiophane. 9 g of α,β'-dimethylfuranidine was passed over alumina at 330° in a current of hydrogen sulfide at the rate of 10 drops per minute. The catalyzate was saturated with sodium hydroxide and extracted with ether. The ether extract was dried with calcium chloride, the ether driven off, and the reaction product distilled from a flask fitted with a dephlegmator.

The resultant α, β'-dimethylthiophane had the following constants:

B.p. 147-148° (742 mm). n_D^{20} 1.4818; d_4^{20} 0.9265. MR_D 35.74. Calculated MR_D 35.68.

Melting point of the compound with $HgCl_2$ (from alcohol): 89°.

7.600 mg substance: 17.270 mg CO_2; 6.810 mg H_2O. 6.310 mg SO_4.
7.980 mg substance: 18.150 mg CO_2; 7.240 mg H_2O. 6.600 mg SO_4.
Found %: C 62.01, 62.07; H 10.03, 10.07; S 27.71, 27.61. $C_6H_{12}S$. Calculated %: C 62.00; H 10.41; S 27.59.

Yield 6.1 g (58.5% of the theoretical). α, β'-Dimethylthiophane has not been described in the literature.

SUMMARY

1. The present paper describes for the first time: a) α, β'-dimethylfuranidine, synthesized by dehydrogenating α,β'-dimethylfuran catalytically with paladinized asbestos; and b) α, β'-dimethylthiophane, synthesized by the catalytic conversion of α, β'-dimethylfuranidine.

2. It has been shown, for the first time, that when α,β'-dimethylfuran and α,β'-dimethylfuranidine are acted upon by ammonia at high temperature in the presence of activated alumina, they are converted into α, β'-dimethylpyrrole and α, β'-dimethylpyrrolidine, respectively. The action of hydrogen sulfide upon α, β'-dimethylfuranidine at 330° in the presence of alumina converts it into α, β'-dimethylthiophane.

3. In the above-described conversion of oxygen-containing heterocyclic compounds into rings containing other hetero atoms, the methyl group located at the β-position of the furan or furanidine ring has no influence on the stability of these rings, provided they possess another methyl group at the α-position: in their behavior in this reaction, α, β'-dimethylfuran and α,β'-dimethylfuranidine most closely resemble α-methylfuran and α-methylfuranidine, respectively, their behavior differing considerably from that of 2,5-dimethylfuran and 2,5-dimethylfuranidine.

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SOME DERIVATIVES OF BENZOTHIAZOLE

III. 2,5,6- and 2,6,7-TRIMETHYLBENZOTHIAZOLES

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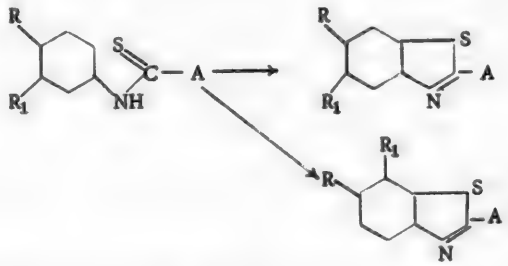
We have previously shown that when meta-substituted thioacetanilides are oxidized, the thiazole ring may be closed at the para as well as at the ortho position to the substituent present in the benzene ring. For instance, when thioacetyl-m-anisidine is oxidized, a mixture of 7- and 5-methoxy-2-methylbenzothiazoles [1] is formed, while oxidation of m-thioacetaminodimethylaniline yields nothing but 7-dimethylamino-2-methylbenzothiazole [2]. Oxidation of thioacetyl-m-nitroaniline has yielded 7-nitro-2-methylbenzothiazole [3].

The 3,4-disubstitution derivatives of thioacetanilide and phenylthiourea can also produce two isomers in this reaction.



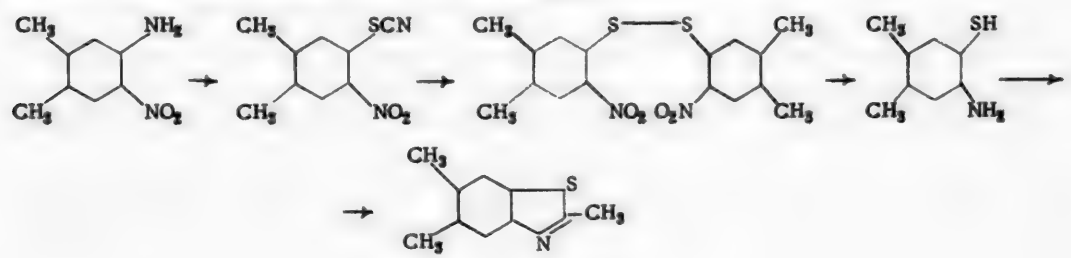
(A = CH_3 or NH_2).

The closure of the thiazole ring at the ortho position to the second substituent group has not been observed up to the present time, however, in the 3,4-disubstitutition derivatives of thioacetanilide and phenylthiourea. Fries and his co-workers [4] secured only one derivative of benzothiazole – 5,6-dimethoxy-2-methylbenzothiazole – when they oxidized 4-thioacetaminoveratrole. Patents [5] indicate that in the 3,4-diethoxy- and 3-methoxy-4-methylmercaptothioacetanilides the thiazole ring is likewise closed at the para position to the alkoxy group.

We proposed to investigate the ring closure of 3,4-disubstitution derivatives of thioacetanilide and phenylthiourea, using derivatives of 4-amino-1,2-xylene.

Oxidizing 4-thioacetamino-1,2-xylene yielded a mixture of bases that fused in the 30-60° range. Trimethylbenzothiazole, with a m.p. of 85-86°, was recovered from this mixture by means of crystallization.

To establish the structure of this compound we synthesized 2,5,6-trimethylbenzothiazole from 5-amino-4-nitro-1,2-xylene. The latter was converted into 4-nitro-5-thiocyano-1,2-xylene, which was then transformed into 2,2'-dinitro-4,5,4',5'-tetramethyldiphenyl disulfide by treating it with sodium sulfite in aqueous solution (cf [6]). This compound was then reduced with zinc dust in acetic acid, the resulting aminothioxylenol being converted into 2,5,6-trimethylbenzothiazole in the usual manner (cf [7]).



This compound was secured as colorless crystals with a m.p. of 85-86°, which exhibited no depression of the mixed melting point with a previously prepared base.

We have been unable as yet to isolate in a pure state the second base produced when 4-thioacetamino-1,2-xylene is oxidized, owing to its high solubility. It is obvious, however, that a mixture of 2,5,6- and 2,6,7-trimethylbenzothiazole is produced during the process.

We oxidized 3,4-dimethylphenylthiourea with an equimolar quantity of bromine at 0-5° in the presence of chloroform (cf [8]), no perbromides being formed under these conditions. This yielded a mixture of 2-aminodimethylbenzothiazoles, from which we managed to isolate two bases, with m.p. of 185-186° and 198-199°, by means of fractional crystallization, first from methanol and then from ethyl alcohol. When the first of these bases was heated with potassium hydroxide (cf [9]) and the resultant salt of aminothioxylenol then processed with acetic anhydride, it yielded 2,5,6-trimethylbenzothiazole, with a m.p. of 85-86°, so that it was 2-amino-5,6-dimethylbenzothiazole. Similarly, the second base, with a m.p. of 198-199°, produced when 3,4-dimethylphenylthiourea was oxidized must be assigned the structure of 2-amino-6,7-dimethylbenzothiazole. By heating this compound with a concentrated aqueous solution of potassium hydroxide and treating the resulting salt of 2-amino-5,6-dimethylthiophenol with acetic anhydride, we secured 2,6,7-trimethylbenzothiazole as colorless crystals with a m.p. of 40-41°.

Thus, when 3,4-dimethylthioacetanilide and 3,4-dimethylphenylthiourea are oxidized, the thiazole ring is closed at the para and ortho positions to the second methyl group, producing in both cases a mixture of 5,6- and 6,7-dimethylbenzothiazoles that contain a methyl or an amino group at the 2 position.

EXPERIMENTAL

(Together with L. I. Nesterova and E.K.Dudorova)

4-Thioacetylamino-1,2-xylene. A mixture of 16.3 g of 4-acetamino-1,2-xylene, with a m.p. of 97-98° [10], and 11.1 g of phosphorus pentasulfide was heated to 75° for one hour (or to 85° for 30 minutes), causing it to darken and fuse.

The melt was dissolved by heating it with 160 ml of ethyl alcohol, the liquid was cooled, and a solution of 20 g of potassium hydroxide in 600 ml of water was added. The next day, the minute tarry precipitate was filtered out of the solution, and the filtrate was heated to 45° for 30 minutes with activated charcoal. After the charcoal had been filtered out, the solution was neutralized with acetic acid and 4-thioacetylamino-1,2-xylene was thrown down as a yellowish crystalline precipitate by passing carbon dioxide through it. The yield was 8.7 g (49% of the theoretical), m.p. 93-95°. Crystallization from ethyl alcohol raised the melting point to 106-107°. Colorless prisms.

Found %: N 7.75. $C_{10}H_{13}NS$. Calculated %: N 7.82.

When the reaction was carried out in benzene, the yield of 4-thioacetylamino-1,2-xylene (m.p. 99°) was 39% of the theoretical.

Oxidation of 4-thioacetylamino-1,2-xylene. A solution of 17.9 g of 4-thioacetylamino-1,2-xylene (m.p. 93-95°) in 400 ml of 4% sodium hydroxide was gradually added, with vigorous stirring, at 6-8° to a solution of 66 g of potassium ferricyanide in 800 ml of water. Stirring was continued for another hour at the same temperature, after which the reaction product was extracted with ether, the extract dried with potash, the ether driven off, and the residue of 18 g distilled in vacuo, a fraction with a b.p. of 130-143° at 7 mm being collected. The yield was 9.6 g (54.2% of the theoretical), m.p. in the 30-60° range.

The preparation was crystallized from 20 ml of gasoline (b.p. 60-80°). The yield was 1.65 g; m.p. 80-82°. Evaporating the filtrate yielded another 0.20 g of a substance with a m.p. of 80-81°. The overall yield was 1.85 g (10.4% of the theoretical). Recrystallization of the substance from gasoline yielded colorless needles with a m.p. of 85-86°, which exhibited no depression of the mixed melting point with 2,5,6-trimethylbenzothiazole (see below).

After the second fraction had been separated from the mother liquor, the gasoline was driven off in vacuo, and the residue converted into a picrate. The latter weighed 16.15 g; m.p. 150-163°. The picrate was boiled with 320 ml of ethyl alcohol, causing the melting point of the insoluble residue (1.65 g) to rise to 187-190°. Recrystallization from ethyl alcohol yielded yellow needles with a m.p. of 194-195°, which exhibited no depression of the mixed melting point with the picrate of 2,5,6-trimethylbenzothiazole (see below).

The mixture of picrates recovered from the alcoholic solution had a m.p. of 150-165°, which remained practically unchanged after repeated crystallizations.

3,4-Dimethylphenylthiourea. A solution of 48.5 g of potassium thiocyanate in 70 ml of water was added, with stirring, to a solution of 1,2,4-xylidine hydrochloride, prepared by adding 45 ml of hydrochloric acid (sp. gr. 1.19) to a suspension of 60.5 g of the freshly distilled and finely pulverized amine in 300 ml of water. The liquid was heated to 102° (oil temperature) on an oil bath until the water had evaporated (12-14 hours). The dry residue was then heated to 102-105° for 2 hours. The reaction product was triturated with 200 ml of water, the insoluble material being filtered out and washed with 500 ml of water until all the chlorine ion was eliminated. The yield was 78 g (86.7% of the theoretical). M.p. 178-180°. Crystallization from ethyl alcohol raised the product's melting point to 181-182°; this melting point was unchanged by further purification. Colorless needles, fairly readily soluble in alcohol, sparingly soluble in benzene.

Found %: N 15.79, 15.68. $C_9H_{12}N_2S$. Calculated %: N 15.55.

Dyson and George [13], who synthesized 3,4-dimethylphenylthiourea by reacting ammonia with dimethyl phenyl mustard oil or 3,4-dimethylphenylcarbamyl chloride, erroneously give a m.p. of 141.5-142.5° for this compound.

Oxidation of 3,4-dimethylphenylthiourea. A solution of 48 g of bromine in 120 ml of chloroform was gradually added at 0-5°, with vigorous stirring, to a suspension of 54 g of finely powdered 3,4-dimethylphenylthiourea in 270 ml of anhydrous chloroform, causing the evolution of hydrogen bromide. Then the reaction mixture was stirred for another 2 hours at 0-5° and set aside to stand overnight.

The nearly colorless precipitate was filtered out, washed with 200 ml of chloroform, and air-dried. It weighed 87-88 g. The hydrobromide was heated in 1000 ml of water until it dissolved, and the solution was alkalinized with aqueous ammonia. After the solution had cooled, the colorless precipitate was filtered out and washed with water. The yield of the mixture of isomeric dimethyl-2-aminobenzothiazoles totaled 52 g (97% of the theoretical). M.p. 155-160°.

The product was crystallized from 155 ml of methanol, 2-amino-5,6-dimethylbenzothiazole settling out as colorless crystals. Weight: 29 g. M.p. 180-181°. The methanol was driven off from the filtrate and the wash fluids, and the residue (weighing 22.7 g, m.p. 149-152°) was crystallized three times from methanol. Weight 6.55 g; m.p. 181-183°. The total yield of 2-amino-5,6-dimethylbenzothiazole was 35.55 g (66% of the theoretical).

Recrystallization from methanol (1:4) raised the melting point to 185-186°; this m.p. was unaffected by further purification. Colorless needles. Slightly soluble in hot water, rather sparingly soluble in cold benzene, more readily soluble in acetone, and readily soluble in ethyl alcohol and methanol.

Found %: N 15.58, 15.64. $C_9H_{10}N_2S$. Calculated %: N 15.72.

Hydrochloride – colorless crystals (from water). Rather sparingly soluble in water (1:100 at 20°).

Hydrobromide – colorless leaflets (from water).

Sulfate – minute colorless needles (from water). Slightly soluble in water (1:125 at 20°), even less soluble in a 2% solution of potassium sulfate (1:800 at 20°).

All the crystallization mother liquors were combined and evaporated to small volume, the product that settled out being filtered out, dried (weight 12.0 g, m.p. 152-155°), and crystallized three times from 5 parts of ethyl alcohol. This yielded 1.20 g of 2-amino-6,7-dimethylbenzothiazole, m.p. 195-197°. Another recrystallization from ethyl alcohol yielded large, slightly brownish prisms with a m.p. of 198-199°, slightly soluble in hot water, very readily soluble in ethyl alcohol, and extremely soluble in methanol.

Found %: N 15.73: $C_9H_{10}N_2S$. Calculated %: N 15.72.

Hydrochloride – colorless prisms (from water). Slightly soluble in water (1:220 at 20°).

Sulfate – minute colorless crystals. Very slightly soluble in water (1:1000 at 20°) and practically insoluble at ordinary temperatures in a 2% solution of potassium sulfate.

4-Amino-5-nitro-1,2-xylene. This was prepared by nitrating 4-acetamino-1,2-xylene and then saponifying the nitroacetyl derivative with an aqueous solution of an alkali [11]. This procedure yielded better results than the method described by Noelting, Braun, and Thesmar [12].

161 g of 4-acetamino-1,2-xylene (m.p. 97-98°) was gradually added, at a temperature that did not exceed 25°, to 415 ml of sulfuric acid (sp. gr. 1.76), with constant stirring. 64 ml of nitric acid (sp. gr. 1.46) was added drop by drop during the course of 2-2.5 hours at 16-17°, with constant stirring, to the thickened mass. After the

nitric acid had been added, the resulting solution was stirred for another 30 minutes and then poured into a mixture of 6 liters of water and 2 kg of ice. The voluminous yellow precipitate that settled was filtered out and washed successively with water, a weak soda solution, and again with water.

The well-squeezed-out paste (weighing 340 g) was saponified by stirring it for 4 hours at 80-90° with a solution of 42 g of sodium hydroxide in 260 ml of water. When it had cooled to 60°, the precipitated crystals of 4-amino-5-nitro-1,2-xylene were filtered out and washed with warm water until the reaction was neutral.

Crystallization from 6 parts of ethyl alcohol yielded the product as lustrous orange-red prisms with a m.p. of 138-140° (Noelting, Braun, and Thesmar give the m.p. as 139-140° [12]). The yield was 66 g (39.7% of the theoretical).

4-Thiocyano-5-nitro-1,2-xylene. 66.4 g of 4-amino-5-nitro-1,2-xylene was heated to 60-70° with 80 ml of sulfuric acid (sp. gr. 1.84), and the thick mass was poured into a mixture of 800 ml of water and 800 g of ice, the amine sulfate settling out as a fine yellow precipitate. The latter was diazotized by adding a solution of 34.5 g of sodium nitrite in 50 ml of water. After the resultant solution had stood for 30 minutes, it was filtered and a solution of 40.75 g of potassium thiocyanate in 120 ml of water was gradually added, with constant stirring, which immediately precipitated the greenish-yellow thiocyanate. The next day the product was filtered out and washed with water until the reaction was neutral. The yield was 79.5 g (95.6% of the theoretical). M.p. 136-139°.

Yellow orthogonal prisms after a single crystallization from ethyl alcohol, m.p. 141-142°. The product was slightly soluble in ethyl alcohol at ordinary temperatures, though readily soluble when heated in the alcohol; soluble in ether and acetone.

Found %: N 13.37. $C_9H_8O_2N_2S$. Calculated %: N 13.45.

2,2'-Dinitro-4,5,4',5'-tetramethyldiphenyl disulfide. 104 g of 4-thiocyano-5-nitro-1,2-xylene (with a m.p. of 136-139°) was boiled for 4 hours with a solution of 10.15 g of 100% sodium sulfite in 1000 ml of water. The flask was shaken frequently, avoiding all shocks. The next day the product was filtered out and washed with 5 liters of water and with 350 ml of ethyl alcohol. The yield was 85 g, (93.5% of the theoretical). M.p. 206-208°.

Two recrystallizations from benzene raised the melting point to 213-214°. Yellow needles. Slightly soluble in acetone, even less soluble in ethyl alcohol, and nearly insoluble in ether.

Found %: N 7.60. $C_{16}H_{16}O_4N_2S_2$. Calculated %: N 7.69.

2,5,6-Trimethylbenzothiazole. a) From 2,2'-dinitro-4,5,4',5'-tetramethyldiphenyl disulfide. A mixture of 72.8 g of 2,2'-dinitro-4,5,4',5'-tetramethyldiphenyl disulfide (m.p. 206-208°) with 138 g of (100%) zinc dust was gradually added, with stirring, to 600 ml of glacial acetic acid heated to 80-90°. When reduction was complete, the mass was stirred for 30 minutes at 100°. Then 187 g of acetic anhydride was added portionwise, and stirring was continued for another 3 hours at 140-145° (bath temperature). The mass was cooled to 70-80°, diluted with 900 ml of water, and then chilled and alkalinized with a concentrated solution of sodium hydroxide, the resultant base being distilled with steam. The crystalline product was filtered out, pulverized, and washed with water. The yield was 52 g (83.5% of the theoretical), m.p. 82-83.5°.

Two recrystallizations from gasoline (b.p. 60-80°) yielded the product as colorless needles with a m.p. of 85-86°, which remained unaffected by subsequent crystallizations.

Found %: N 7.78. $C_{10}H_{11}NS$. Calculated %: N 7.91.

b) From 2-amino-5,6-dimethylbenzothiazole. A mixture of 14.24 g of 2-amino-5,6-dimethylbenzothiazole with a m.p. of 180-181°, 40 g of potassium hydroxide, and 25 ml of water was heated, with stirring, to 130-135° (temperature of the mass) until no more ammonia was evolved, which usually took 15-18 hours. The mass was slowly cooled, the potassium salt of the aminothioxylenol that settled out being filtered out on a glass filter and thoroughly squeezed out. The salt was then transferred to a three-necked flask fitted with a stirrer and an inclined condenser, and 50 ml of acetic anhydride was gradually added. Then the reaction mass was heated, with stirring, for 3 hours at 180-190° (oil temperature) on an oil bath, 10 ml of acetic acid being driven off. 6 ml of acetic anhydride was added, and the mixture was refluxed for 1 hour. After it had cooled, the mass was diluted with water and alkalinized with a 30% solution of sodium hydroxide, the 2,5,6-trimethylbenzothiazole being driven off with steam. The product was filtered out, washed with water, and dried. The yield was 11-12 g (77-84% of the theoretical). M.p. 80-81°.

Double recrystallization from gasoline (b.p. 60-80°) yielded colorless needles with a m.p. of 85-86°, which exhibited no depression of the mixed melting point with the 2,5,6-trimethylbenzothiazole synthesized by the first method.

Picrate – lustrous yellow needles (from ethyl alcohol), m.p. 194-195°.

The methiodide was secured by refluxing the base for 15 hours with a 50% excess of methyl iodide on a boiling water bath, the yield being 78.9% of the theoretical. Nearly colorless prisms (from ethyl alcohol). M.p. 254-256°.

Found %: N 4.32. $C_{11}H_{14}NSI$. Calculated %: N 4.38.

The ethiodide was similarly prepared from ethyl iodide. Slightly grayish prisms (from ethyl alcohol). M.p. 218-219°.

Found %: N 4.16. $C_{12}H_{16}NSI$. Calculated %: N 4.25.

2,6,7-Trimethylbenzothiazole. 1.78 g of 2-amino-6,7-dimethylbenzothiazole (0.01 mole) was heated, with stirring, with 5 g of potassium hydroxide and 4 ml of water on an oil bath to 135-140° (oil temp.) until no more ammonia was evolved, which usually took 35-40 hours. After the mixture had cooled, the precipitated potassium salt of the aminothioxylenol was filtered out on a glass filter and then transferred to a flask containing 6.5 ml of acetic anhydride. The mixture was stirred and heated for 2 hours with an inclined condenser on an oil bath at 160-170° (oil temp). Then 2 ml of acetic anhydride was added, and the mixture was refluxed for 1 hour, diluted with water, and alkalinized, the resultant base being distilled with steam. After extraction with ether and drying with potash, the ether was driven off, and the residue (0.70 g) was distilled in vacuo, a fraction with a b.p. of 142-147° at 25 mm being collected. The yield was 0.62 g (35% of the theoretical). Upon cooling the 2,6,7-trimethylbenzothiazole solidified completely into a colorless crystalline mass.

Recrystallization from gasoline yielded the product as large colorless prisms with a m.p. of 40-41°, this melting point remaining unaffected by subsequent crystallizations.

Found %: N 7.90. $C_{10}H_{11}NS$. Calculated %: N 7.91.

Picrate – yellow needles (from ethyl alcohol). M.p. 157-158°.

The methiodide was secured by refluxing the base for 11 hours with a 35% excess of methyl iodide on a water bath, the yield being 69.4% of the theoretical. Nearly colorless prisms (from ethyl alcohol), m.p. 205-206°.

Found %: N 4.21. $C_{11}H_{14}NSI$. Calculated %: N 4.38.

The ethiodide was similarly prepared by refluxing the base for 20 hours with ethyl iodide. The yield was 60% of the theoretical. Nearly colorless prisms (from ethyl alcohol). M.p. 207°.

Found %: N 4.28. $C_{12}H_{16}NSI$. Calculated %: N 4.25.

SUMMARY

1. It has been shown that when 3,4-dimethylthioacetanilide and 3,4-dimethylphenylthiourea are oxidized, the thiazole ring is closed at the ortho and para positions to the methyl group, yielding a mixture of 5,6- and 6,7-dimethylbenzothiazoles, which contain a methyl or an amino group, respectively, at the 2 position.

2. The properties of these bases and of some of their derivatives have been investigated.

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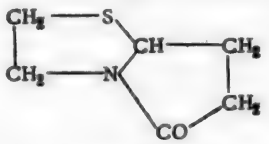
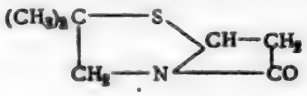
THIAZOLIDINE-4-CARBOXYLIC ACID AND ITS DERIVATIVES

I. THE COMPOUND WITH A THIAZOLIDINE-PYRROLIDONE RING SYSTEM

I. T. Strukov

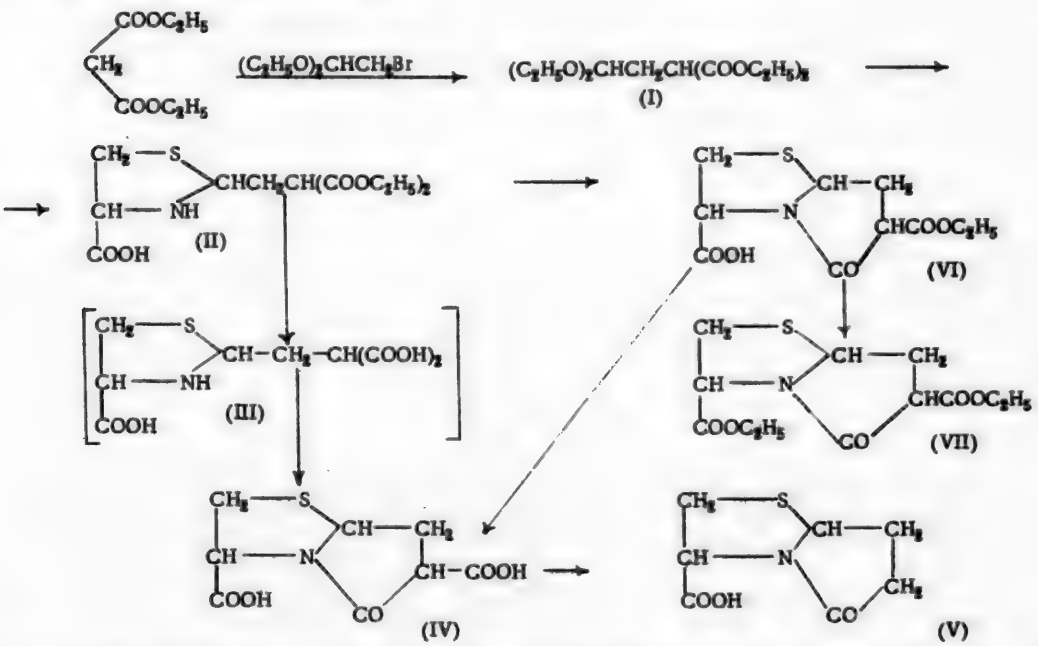
The thiazolidine-pyrrolidone or thiazolidone-γ-lactam ring system is interesting because of its closeness to the thiazolidine- β-lactam system that is the basis of penicillin and its analogs.





This research has been undertaken chiefly to determine how the γ-lactam ring can be closed, using the corresponding substitution derivatives of thiazolidine-4-carboxylic acid, and to make a study of the properties of these compounds.

The synthesis was effected as follows:



Condensing bromodiethyl acetal with malonic ester yielded the ethyl ester of α-carbethoxy-γ,γ-diethoxybutyric acid (I), which yielded the ethyl ester of α-carbethoxy-β-(4-carboxythiazolidyl-2)-propionic acid (II) when heated with l-cysteine hydrochloride. When (I) is heated with cysteine hydrochloride for a long time, the reaction goes further, the compound (II) being converted into the γ-lactam of α-carbethoxy-β-(4-carboxythiazolidyl-2)-propionic acid (VI) and the ethyl ester of this acid (VII).

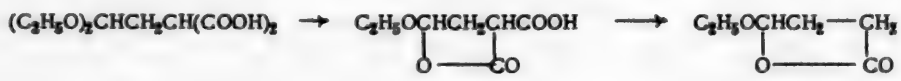
The pyrrolidone (γ-lactam) ring may be closed in a neutral medium as well as by heating the hydrochloride (II); this occurs, for example, when the sodium salt of (II) or the free α-carboxy-β-(4-carboxythiazolidyl-2)-propionic acid (III) is heated. The γ-lactam ring is formed fairly easily.

In aqueous solution the hydrochlorides of 2-substitution derivatives of thiazolidine-4-carboxylic acid are partially hydrolyzed, apparently because of the presence of the adjoining carboxyl group. The primary amino group of cysteine may possess more highly basic properties than the secondary amino group of the thiazolidine ring that is substituted at the 2 position. As a rule, when water is used to dilute the reaction mass produced by condensing cysteine hydrochloride with the ethyl ester of α-carbethoxy-δ,δ-diethoxybutyric acid, a thiazolidine compound is precipitated, though the latter's yield is much higher when the solution is neutralized until its reaction is faintly acid.

Somewhat more iodine is required for the iodometric titration of the sodium salt of (II) than is needed for oxidation, the substance breaking down into cystine and the corresponding aldehyde. This agrees fully with the findings of Ratner and Clarke [1] for thiazolidine-4-carboxylic acid. The iodometric method cannot be employed for the quantitative determination of thiazolidine-4-carboxylic acid or its derivatives because the aldehyde produced in the reaction reacts with the iodine. Inasmuch as the rate at which the cysteine is produced in the cleavage of the thiazolidine ring is much higher than the velocity of the reaction between the iodine and the aldehyde, iodine may be used as a reagent for a thiazolidine ring that is unacylated at the nitrogen atom.

When the γ-lactam of α-carbethoxy-β-(4-carboxythiazolidyl-2)-propionic acid (VI) is saponified with an alkali, it yields the sodium salt of the γ-lactam of α-carboxy-β-(4-carboxythiazolidyl-2)-propionic acid, from which the free acid (IV) may be readily secured. Decarboxylation of the latter yields the γ-lactam of β-(4-carboxythiazolidyl-2)-propionic acid (V). The chemical properties of this compound differ but little from those of the N-acylated thiazolidine-4-carboxylic acids. It is stable in the cold in acid or alkali media, but is broken down rather easily when heated with solutions of caustic alkalies, a thiol group being found in the decomposition products. It hardly reacts with an iodine solution.

It seemed possible to prepare the compound (V) from the ethyl ester of α-carbethoxy-δ,δ-diethoxybutyric acid (I) by saponifying it, decarboxylating it, and condensing the resultant δ,δ-diethoxybutyric acid with cysteine. We were unable to synthesize it, however: α-carboxy-δ,δ-diethoxybutyric acid (VIII) is readily converted into α-carboxy-δ-ethoxy-γ-butyrolactone (IX), decarboxylation of which yields γ-ethoxy-β-butyrolactone (X):



(VIII) (IX) (X)

Acylation of the thiazolidine ring on the nitrogen makes it fairly stable. It seemed that, if the acylating agent were to set up an instable bond with the nitrogen, the resulting compound might be of some interest from the standpoint of chemotherapy, since diacylation destroys the stability of the thiazolidine ring. Ethyl chloroformate was used for acylation. N-Carbethoxythiazolidine-4-carboxylic acid resembles N-acetylthiazolidine-4-carboxylic acid in all respects.

EXPERIMENTAL

Preparation of the diethyl ester of α-carbethoxy-δ,δ-diethoxybutyric acid. 200 ml of absolute alcohol was placed in a 500-ml round-bottomed flask fitted with a reflux condenser terminated with a calcium-chloride tube, and 14.4 g of metallic sodium was gradually added. After all the sodium had dissolved, the flask was cooled to 40-50°, and then 100 g of diethyl malonate and 128 g of bromodiethyl acetal were added [2]. The flask was heated on an oil bath for 48 hours at a bath temperature of 100-110°. Then the ethyl alcohol was driven off on the oil bath, the flask contents chilled to 15-20°, the residue treated with 200 ml of water, and the oil that separated out extracted twice with ether. The ether solution was washed with water and dried with calcined sodium sulfate, after which the ether was driven off, and the residue fractionated at a 9-mm vacuum.

The ethyl ester of α-carbethoxy-δ,δ-diethoxybutyric acid is a colorless liquid, faintly aromatic, with a b.p. of 146-147° at 9 mm; $[n]_D^{20}$ 1.4275. It is freely soluble in many organic solvents. The yield was 97 g, or 56.5% of the theoretical.

3.574 mg substance: 7.376 mg CO_2; 2.832 mg H_2O. Found %: C 56.28; H 8.87.
$C_{13}H_{24}O_6$. Calculated %: C 56.48; H 8.76.

Preparation of γ-ethoxy-β-butyrolactone (X). 10 grams of the ethyl ester of α-carbethoxy-δ,δ-diethoxybutyric acid, 30 ml of ethyl alcohol, 20 ml of water, and 7.5 ml of a 29% solution of sodium hydroxide were refluxed for 1 hour. The solution became faintly alkaline. It was concentrated to a thick syrup in vacuo on a water bath. Then 100 ml of ether, 2 ml of concentrated sulfuric acid, and 10 ml of water were added, and the mass was

vigorously agitated. The ether solution was decanted. Ether extraction was repeated two more times. Then the ether extract was dried with calcined sodium sulfate, the ether driven off on a water bath, and the residual oil dried in vacuo This yielded 6.5 g of technical α-carboxy-γ-ethoxy-γ-butyrolactone. It is obvious that α-carboxy-γ, γ-diethoxybutyric acid is unstable, being readily converted to the corresponding butyrolactone, alcohol being split off. In direct titration of this acid, 0.1353 g required 7.8 ml of 0.1 N sodium hydroxide solution, equivalent to 100.6%, based on $C_7H_{10}O_5$. The presence of the γ-lactone ring may be established quantitatively by means of back titration. Thus, 16 ml of a 0.1 N sodium hydroxide solution was added to 0.1353 g of the substance, the whole being heated to boiling and left to stand for 18 hours. 0.36 ml of 0.1 N NaOH was back titrated, equivalent to 100.6%, based on the acid $C_7H_{10}O_5$, in which the free and the esterified carboxyl groups were back-titrated.

The α-carboxy-γ-ethoxy-γ-butyrolactone was decarboxylated on an oil bath at 150° until no more carbon dioxide was evolved. The residue was fractionated in vacuo, yielding a fraction with a b.p. of 88-90° at 10 mm. A colorless liquid with the odor of stearin, freely soluble in alcohol, ether, and ethyl acetate, and insoluble in water.

3.642 mg substance: 7.953 mg CO_2; 2.570 mg H_2O. 5.116 mg substance: 10.161 mg CO_2; 3.638 mg H_2O. Found %: C 55.31, 55.16; H 7.89, 7.95. $C_6H_{10}O_3$. Calculated %: C 55.35; H 7.75.

The substance contained a lactone group, disclosed by back-titration after it had been heated with a sodium hydroxide solution. 20 ml of 0.1 N NaOH was added to 0.1068 g of the substance, and the mixture was refluxed for 1 hour. After the mixture had cooled, 11.7 ml of 0.1 N NaOH was back-titrated, equivalent to 100.9%, based on γ-ethoxy-γ-butyrolactone ($C_6H_{10}O_3$).

Ethyl ester of α-carbethoxy-β-(4-carboxythiazolidyl-2)-propionic acid (II). 5 g of l-cysteine hydrochloride was dissolved in 2 ml of water, 8.5 g of the ethyl ester of α-carbethoxy-γ, γ-diethoxybutyric acid was added, and the whole was heated, with vigorous stirring, on a boiling water bath for 10 minutes. The emulsion produced at the start of the reaction quickly disappeared, a yellow homogeneous mass being formed. It was transferred to 100 ml of water, with constant stirring, crystallization setting in at once. The hydrochloric acid was neutralized by carefully adding 23 ml of a 5% solution of sodium bicarbonate and allowing the mass to stand for 24 hours at 0 to +2°. Then the precipitate was filtered out, washed with ice water, dried at 30-40°, and washed with ether in a separate little flask. The yield was 6.5 g or 68% of the theoretical. The substance was recrystallized from 40 ml of water; m.p. 124-125°. The ethyl ester of α-carbethoxy-β-(4-carboxythiazolidyl-2)-propionic acid (lamellae) is sparingly soluble in cold water and freely soluble in hot water, sparingly soluble in ether, soluble in alcohol, ethyl acetate, acetone, and chloroform, hardly soluble in benzene, and insoluble in gasoline; it is freely soluble in alkalies. When a 4% aqueous solution of the sodium salt is stored, the substance decomposes, yielding hexahedral crystals of l-cystine, the odor of acetaldehyde malonic ester being perceptible. A freshly prepared aqueous solution does not exhibit a reaction for the thiol group with ammonia and sodium nitroprusside, though after it has been heated with a 5% solution of sodium hydroxide the thiol group is revealed by the bright crimson color produced by sodium nitroprusside. When the Na salt is titrated in a water-alcohol medium with a 0.1 N solution of iodine, the latter is quickly decolorized, and, although the titration endpoint is readily detectable, the results obtained are too high, owing to the oxidation of the aldehyde produced during the reaction. When the titrated solution is allowed to stand, a precipitate of l-cystine soon begins to settle out: m.p. 220-222° (true hexagonal lamellae). 0.700 g of the substance was dissolved in 20 ml of ethyl alcohol and back-titrated with 2.3 ml of 0.1 N NaOH, equivalent to 100.5% in terms of $C_{12}H_{19}O_6NS$.

6.027 mg substance: 0.244 ml N_2 (21°, 746.5 mm). Found %: N 4.62. $C_{12}H_{19}O_6NS$. Calc.%: N 4.59.

Cleavage of the thiazolidine ring by mercuric chloride. 1 g of the ethyl ester of α-carbethoxy-β-(4-carboxythiazolidyl-2)-propionic acid, 0.9 g of mercuric chloride, and 10 ml of methanol were rapidly stirred, causing dissolution at first, though the solution quickly began to turn cloudy, a white crystalline complex salt of cysteine and mercuric chloride settling out. To complete cleavage, we added 1 ml of water, shook the mixture up, and allowed it to stand for 1 hour. Then the precipitate was filtered out, and the filtrate evaporated in vacuo to dryness. The crystalline residue was treated with 50 ml of ether, the acetaldehyde malonic ester dissolving and the solution being filtered to free it of the precipitate. The precipitate weighed about 1.3 g. The ether solution was washed with 10 ml of 2 N HCl, and then twice with water, after which it was dried with a calcined sodium sulfate and the ether driven off. This left 0.5 g of a light-yellow liquid, which reduced silver from a complex ammoniacal silver salt.

γ-Lactam of α-carbethoxy-β-(4-carboxythiazolidyl-2)-propionic acid (VI). 2.6 ml of a 20% alcoholic solution of sodium hydroxide (in methanol) was added to 4 g of the ethyl ester of α-carbethoxy-β-(4-carboxythiazolidyl-2)-propionic acid in 30 ml of methanol. The acid dissolved. The reaction must be neutral and not alkaline. The methanol was driven off, the residue being heated on a boiling water bath for 4 hours. This produced a yellow hyaline mass, which dissolved completely in 30 ml of water. The substance settling out when the solution was acidulated with 2 ml of 40% sulfuric acid, was extracted with ethyl acetate. The ether extract was washed with 8 ml of 40% sulfuric acid, washed twice with water, and dried with calcined sodium sulfate. The ethyl acetate was driven off, and the remaining light-yellow oil dried in a 10-mm vacuum on a boiling water bath, yielding 2.7 g of the substance.

A very thick, light-yellow oil, insoluble in water and freely soluble in alcohol, ether, chloroform, benzene, and a sodium hydroxide solution. The potential thiol group was disclosed by a reaction with sodium nitroprusside after the substance had been heated for 1-2 minutes with a 20% solution of sodium hydroxide. The solution decolorized iodine extremely slowly. Titration with a 0.1 N solution of sodium hydroxide in an alcoholic solution yielded 101.1% and 101.3%, based on $C_{10}H_{13}O_5NS$ as a monocarboxylic acid.

0.3340 g substance: 0.2900 g $BaSO_4$. 0.3140 g substance: 0.2718 g $BaSO_4$. 6.000 mg substance: 2.40 ml 0.01 N H_2SO_4. Found %: S 11.92, 11.88; N 5.60. $C_{10}H_{13}O_5NS$. Calc. %: S 12.35; N 5.40.

γ-Lactam of α-carboxy-β-(4-carboxythiazolidyl-2)-propionic acid (IV). 15 g of the γ-lactam of α-carbethoxy-β-(4-carboxythiazolidyl-2)-propionic acid was dissolved in 100 ml of methanol, and 23 g of a 20% solution of sodium hydroxide in methanol was added. A crystalline precipitate of the sodium salt soon began to settle out. The reaction mass was refluxed for 6 hours at 50-60° to complete saponification. After the mass had cooled, the precipitate was filtered out, washed twice with a small quantity of cold methanol, and dried in a vacuum desiccator. This yielded 11.2 g of the sodium salt—a light-yellow powder that blazed brightly. The salt was hygroscopic.

Found %: Na 16.4. $C_5H_7O_5NSNa_2$. Calculated %: Na 16.73.

10 g of the resultant sodium salt was treated with 20 ml of 25% sulfuric acid, the dicarboxylic acid produced being extracted eight to ten times with ether. The ether solution was dried with calcined sodium sulfate, and the ether was driven off until the volume totaled 10-15 ml. As the ether evaporated, large crystals soon began to settle out in the crystallizer; they were filtered out and washed with a small quantity of ether. The yield was 3.6 g. Large prisms from an acetone-benzene mixture, m.p. 134-135° (with decomp.), freely soluble in water, acetone, alcohol, and ethyl acetate, sparingly in ether, and insoluble in benzene. The potential thio group was detected in the same way as for the compound (VI). It reacted very slowly with an iodine solution. Titration with 0.1 N solution of sodium hydroxide yielded 99.0-99.1%, based on the dicarboxylic acid $C_5H_9O_5NS$.

5.713 mg substance: 0.289 ml N_2 (21.7°, 751 mm). Found %: N 5.8. $C_5H_9O_5NS$. Calc.%: N 6.06.

γ-Lactam of β-(4-carboxythiazolidyl-2)-propionic acid (V). When the γ-lactam of α-carboxy-β-(4-carboxythiazolidyl-2)-propionic acid was heated to 130-140° at a vacuum of 10 mm for 1.5 hours in a Würtz flask, CO_2 was liberated. The residual yellow oil quickly crystallized upon cooling. The γ-lactam was recrystallized from 1:3 acetone. Large prisms with a m.p. of 137-137.5°, freely soluble in water, alcohol, and acetone, less so in ethyl acetate, ether, and chloroform, and insoluble in benzene. An aqueous solution reacts very slowly with iodine. The potential thiol group was detected as in the case of the compound (VI). It titrated as a monocarboxylic acid with a 0.1 N solution of NaOH, yielding 99.2-99.5%, based on $C_7H_9O_3NS$.

8.023 mg substance: 4.36 ml 0.01 N H_2SO_4. 8.151 mg substance: 4.38 ml 0.01 N H_2SO_4. Found %: N 7.61, 7.53. $C_7H_9O_3NS$. Calculated %: N 7.49.

The compound (V) does not precipitate a complex salt of cysteine and $HgCl_2$ when treated with a solution of mercuric chloride, which is evidence of the stability of the thiazolidine ring when acetylated on nitrogen.

γ-Lactam of α-carbethoxy-β-(4-carbethoxythiazolidyl-2)-propionic acid (VII). This compound was readily produced by heating l-cysteine hydrochloride for 2 hours with the ethyl ester of α-carbethoxy-γ,γ-diethoxybutyric acid. Small quantities of the compound (VI) were produced at the same time, which indicates how easily the carboxyl group of the thiazolidine ring can be esterified.

5 g of cysteine hydrochloride was heated, with stirring, for 2 hours with 8.5 g of the ethyl ester of α-carbethoxy-γ,γ-diethoxybutyric acid. The resultant thick yellow oil was treated with 50 ml of ether and 20 ml of water. The ether solution was separated, washed (while shaken vigorously) with 10 ml of 40% sulfuric

acid, and then with 20 ml of a 5% solution of sodium bicarbonate and with water, and dried with calcined sodium sulfate. The ether solution was filtered, and the ether driven off on a water bath. The residual ether was eliminated in vacuo, leaving behind a thick, non-crystallizing, light-yellow oil; it was insoluble in water, though freely soluble in alcohol, ether, acetone, and chloroform. The potential thiol group was detected as indicated above. It reacts hardly at all with iodine in an alcoholic solution. Saponification yields the compound (IV) with a m.p. of 132-134° (with decomp.).

Found %: N 5.01, 4.9 $C_{12}H_{17}O_5NS$. Calculated %: N 4.87.

N-Carbethoxythiazolidine-4-carboxylic acid. 3 g of the calcium salt of thiazolidine-4-carboxylic acid, 30 ml of water, and 2 g of ethyl chloroformate were agitated together for 5 minutes. The calcium salt dissolved, the liquid becoming transparent. The next day the solution was evaporated in vacuo on a water bath. The residue was processed with ether, the ether solution being dried with calcined sodium sulfate and filtered. Large octahedra formed when the ether was slowly evaporated. They were filtered out and washed with a small amount of anhydrous ether. The yield was 2.5 g; m.p. 96-97°. The substance is very soluble in hot water, alcohol, ether, benzene, chloroform, and ethyl acetate, and insoluble in gasoline. It does not decolorize an iodine solution. It does not produce a complex salt of cysteine and mercuric chloride when reacted with a solution of $HgCl_2$, which is evidence that the thiazolidine ring is stabilized by the presence of a carbethoxy group attached to the nitrogen atom.

Titration of 0.1035 g of the substance with a 0.1 N solution of sodium hydroxide used up 5 ml of the alkali, equivalent to 99.01%, based on N-carbethoxythiazolidine-4-carboxylic acid.

3.571 mg substance: 0.214 ml N_2 (20°, 744 mm). 7.261 mg substance: 0.446 ml N_2 (24.5°, 712 mm). Found %: N 6.82, 6.87. $C_7H_{11}O_4NS$. Calculated %: N 6.82.

SUMMARY

1. Several thiazolidine-pyrrolidone-carboxylic compounds have been synthesized from l-cysteine hydrochloride and the diethyl ester of β, β-diethoxyethylmalonic acid.

2. N-Carbethoxythiazolidine-4-carboxylic acid has been synthesized.

The physical and chemical properties of these compounds resemble those of the N-acylthiazolidine-4-carboxylic acids.

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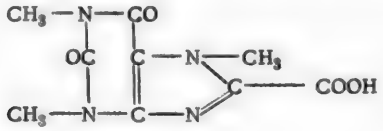
THE 8-SUBSTITUTION DERIVATIVES OF METHYLATED XANTHINES

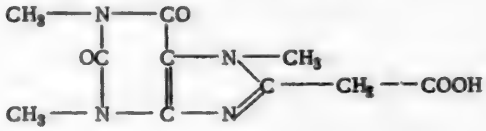
II. SYNTHESIS OF β-(CAFFEINE-8)-PROPIONIC ACID

E. S. Golovchinskaya and E. S. Chaman

In a previous report [1], one of the present authors has described caffeine-8-aldehyde. This compound is formed, with a high yield, from 8-methylcaffeine [2]. The use of caffeine-8-aldehyde as a raw material has opened up extensive prospects for the synthesis of various derivatives of caffeine, especially monobasic and dibasic aliphatic acids with three-membered carbon chains, substituted at the 8 position.

Only very few caffeine derivatives substituted at the 8 position are known at the present time. Two representatives of this group are known: caffeine-8-carboxylic acid [3] and caffeine-8-acetic acid [4]:

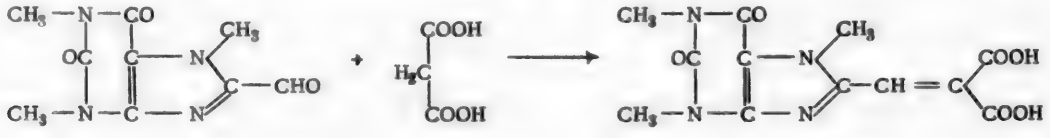




Both of these acids are highly unstable; they are readily decarboxylated, being converted into caffeine and 8-methylcaffeine, respectively. There are no descriptions in the literature of compounds with elongated chains or of unsaturated and dibasic acids of this series.

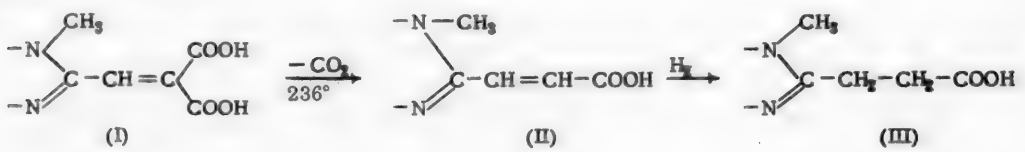
It might have been supposed that lengthening the aliphatic chain and, hence, increasing the distance between the carboxylic group and the caffeine ring would diminish the influence of the latter upon that group, thus producing more highly stable compounds. In the patent literature there is a description of a method for preparing methylated derivatives of xanthine-8-carboxylic acids, involving the acylation of 2,6-dihydroxy-4,5-diaminopyrimidine and its methylated homologs with dicarboxylic aliphatic acids [5]. Closure of the imidazole ring in the resultant acylated diamines leads to the formation of xanthine, as well as mono- and dimethylxanthine, with an aliphatic acid substituted at the 8 position. This method was employed to synthesize theophylline-8-propionic acid and other compounds. Further methylation of these acids would apparently have yielded the corresponding derivatives of caffeine. This cumbersome and complicated reaction pattern does not profide satisfactory yields of the end product, whereas synthesis employing caffeinaldehyde ensures high yields in every stage of the process.

The first stage of this synthesis – condensing caffeinaldehyde with malonic acid in glacial acetic acid – results in the formation of caffeine-8-methylenemalonic acid (I):



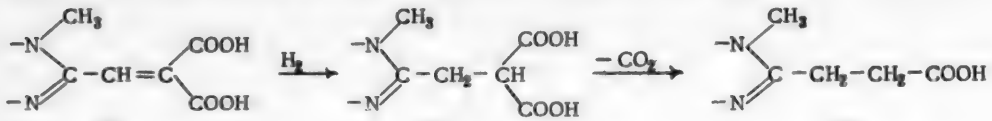
(I)

This acid proved to be a rather stable compound, carbon dioxide being split out only upon fusion (236°), which converted the acid into β-(caffeine-8)-acrylic acid (II). Hydrogenating the latter yielded β-caffeine-8-propionic acid (III):



(I) (II) (III)

Another possible synthesis procedure involves the preliminary hydrogenation of caffeine-8-methylenemalonic acid, followed by decarboxylation of the resultant caffeine-8-isosuccinic acid (IV):

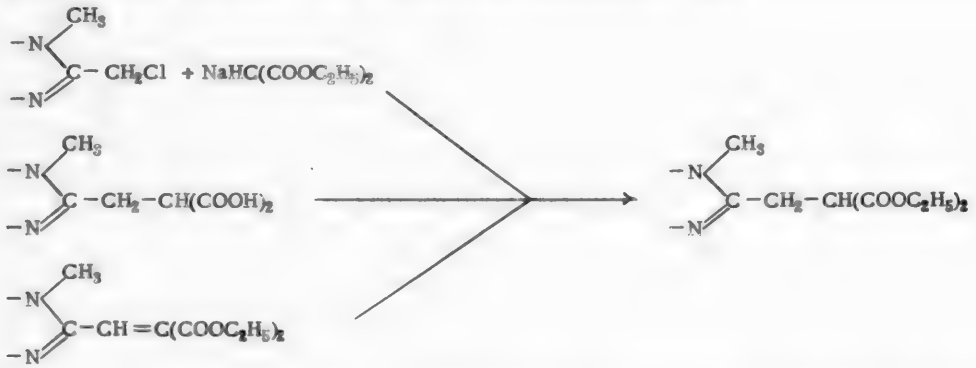


(I) (IV) (III)

High yields of β-caffeinepropionic acid were secured by both methods. Partial decarboxylation of caffeine-methylenemalonic acid and hydrogenation with Raney's nickel of an aqueous solution of the sodium salt of the caffeineacrylic acid (II) prepared from it yielded an extremely stable crystalline substance with a m.p. of 232-233°, β-(caffeine-8)-propionic acid (III), which we were unable to decarboxylate, either by heating it above its melting point or even by heating it to high temperatures with quinoline. Hydrogenating the sodium salt of caffeinemethylenemalonic acid under the same conditions yielded an acid with a m.p. of 230-232°, which gave off no carbon dioxide even when heated to 250-260° and greatly resembled β-(caffeine-8)-propionic acid in appearance and in solubility in water and organic solvents. The mixed melting point of these two acids exhibited no depression.

The unexpected similarity in the physicochemical properties of these two compounds and the absence of any depression of their mixed melting point led us at first to believe that the saturated dicarboxylic acid (IV) is so unstable that it is readily decarboxylated at the instant of its formation or during its recovery from its sodium salt. This assumption was nullified, however, by the results of elementary analysis and titration, which bore out that two acids – a monobasic and a dibasic one – were produced in these reactions. Further research also demonstrated that the synthesized dicarboxylic acid gave off carbon dioxide when heated to 130° with quinoline, yielding β-(caffeine-8)-propionic acid.

There was a considerable difference between the melting points of the ethyl esters of these two acids, and their mixed melting point exhibited a marked depression. The diethyl ester of caffeine-8-isosuccinic acid, with a m.p. of 101°, was likewise synthesized by reacting 8-chloromethylcaffeine with sodium malonic ester in absolute toluene. This ester proved to be the same as the ester of the dicarboxylic acid described above, and as the ester produced by hydrogenating the diethyl ester of caffeine-8-methylenemalonic acid (I).



Saponifying this ester in an acid medium involved partial decarboxylation and resulted in the formation of β-(caffeine-8)-propionic acid, while esterification of the latter yielded the ester with an m.p. of 136°.

These reactions showed the caffeine-8-isosuccinic acid was an extraordinarily stable compound, in contrast to other dicarboxylic acids with two carboxylic groups on a single carbon atom. They likewise constituted a rather rare instance of the absence of depression of the mixed melting point of two distinct, though related, compounds, whose properties and melting points happen to coincide.

β-(Caffeine-8)-propionic acid was identified via several of its esters, including alkyl aminoethyl esters. The latter were prepared by reacting the acid chloride with alkyl aminoethanols.

In our investigation of the reaction involved in the formation of the acid chloride by heating the acid with a large excess of thionyl chloride we secured a compound that contained 29 55% of chlorine. It proved to

be β-(caffeine-8)-dichloropropionyl chloride, with both of the chlorine atoms in the side chain. The only way we could secure the acid chloride of the acid unsubstituted by chlorine was by cautiously heating the acid with a slight excess of thionyl chloride (8-10%) in absolute benzene. This acid chloride proved to be so unstable that we could not purify it for analysis, inasmuch as it was partially hydrolyzed during crystallization, even from absolute benzene. Still there is no doubt about the structure of the acid chloride, since the action of ammonia upon it produced a nearly quantitative yield of an amide that was the same as the amide formed from the methyl ester of β-(caffeine-8)-propionic acid when reacted with aqueous ammonia.

The authors wish to express their heartfelt gratitude to Prof. O. Yu. Magidson for his interest in the present research.

EXPERIMENTAL

(Caffeine-8)-methylenemalonic acid. 44.7 g of 8-caffeinaldehyde, 23 g of malonic acid (prepared by the V. M. Rodionov and A. A. Zvorykina method [6]), and 75 ml of glacial acetic acid were stirred together while heated to 90-95° on a water bath for 5 hours. The cooled reaction mass was filtered, the precipitate being washed with glacial acetic acid and ether and then dried. The yield was 51 g, or 82% of the theoretical. The product was crystallized from 1:60 glacial acetic acid. A yellow powder with an m.p. of 235-236° (with decomposition), insoluble in water, alcohol, chloroform, and other organic solvents, and soluble in a solution of $NaHCO_3$, giving off CO_2. It settles out of an acidulated aqueous solution of the sodium salt in linked clusters of minute needles.

6.280 mg substance: 8.22 ml 0.01 N H_2SO_4. 5.132 mg substance: 6.67 ml 0.01 N H_2SO_4. Found %: N 18.35, 18.39. $C_{12}H_{12}O_6N_4$. Calculated %: N 18.18.

Diethyl ester of (caffeine-8)-methylenemalonic acid. 3 grams of (caffeine-8)-methylenemalonic acid was heated on a boiling water bath for 6 hours with a mixture of 50 ml of absolute ethyl alcohol and 1 g of sulfuric acid (1.84). As the mixture cooled, 1.85 g of the ester, with an m.p. of 181-183°, crystallized out. Another 0.35 g of the ester was recovered from the filtrate by the usual procedures. The yield totaled 2.2 g, or 62% of the theoretical. The ester was crystallized from alcohol (1:10) for analysis. Faintly yellowish-green minute silky needles with an m.p. of 183-184°.

6.708 mg substance: 7.33 ml 0.01 N H_2SO_4. 6.435 mg substance: 7.13 ml 0.01 N H_2SO_4. 3.531 mg substance: 6.835 mg CO_2; 1.678 mg H_2O. Found %: C 52.79; H 5.31; N 15.39, 15.49. $C_{16}H_{20}O_6N_4$. Calculated %: C 52.75; H 5.49; N 15.39.

β-(Caffeine-8)-acrylic acid. 1.5 grams of (caffeine-8)-methylenemalonic acid was heated for 50-60 minutes with 7 ml of quinoline at a bath temperature of 150-160°. The caffeinacrylic acid that settled out upon cooling was filtered and washed with dilute HCl and with water. Then it was dissolved in a solution of $NaHCO_3$ and precipitated by acidulating the solution. The yield was 0.7 g. The quinoline filtrate was agitated 2 or 3 times with a $NaHCO_3$ solution. The bicarbonate solution was washed repeatedly with diethyl ether and then acidulated with hydrochloric acid (1.19) until its reaction was faintly acid with Congo red. This yielded another 0.1 g of the caffein-acrylic acid. The total yield was 0.8 g, or 62.5% of the theoretical. A yellow, finely crystalline substance, with an m.p. of 269-271° (with decomposition). It was crystallized from methyl ethyl ketone (1:100), from chlorotoluene (1:120) and from butyl alcohol (1:160), as thin, transparent, rhombic lamellae. It is insoluble in water, ethyl alcohol, or chloroform.

4.544 mg substance: 6.85 ml 0.01 N H_2SO_4. 3.621 mg substance: 5.46 ml 0.01 N H_2SO_4. Found %: N 21.10, 21.11. $C_{11}H_{12}O_4N_4$. Calculated %: N 21.21.

Ethyl ester of β-(caffeine-8)-acrylic acid. 2 grams of caffeinacrylic acid was heated for 6 hours with a mixture of 80 ml of absolute ethyl alcohol and 0.5 g of sulfuric acid (1.84). After the solution had cooled, 1.9 g of the ester crystallized out. The filtrate was processed in the usual manner, yielding another 0.2 g of the ester. The ester was purified by crystallizing it from alcohol. The total yield was 2.0 g (90% of the theoretical). Faintly colored minute needles, with an m.p. of 207-208°, very soluble in chloroform. It crystallizes from alcohol, carbon tetrachloride, and ethyl acetate. It is insoluble in water.

5.386 mg substance: 7.40 ml 0.01 N H_2SO_4. 7.015 mg substance: 9.54 ml 0.01 N H_2SO_4. Found %: N 19.23, 19.04. $C_{13}H_{16}O_4N_4$. Calculated %: N 19.17.

β -(Caffeine-8)-propionic acid. 0.5 gram of caffeinacrylic acid was dissolved in 18.8 ml of 0.1N NaOH, 0.5 g of a Raney nickel catalyst was added, and the solution was hydrogenated at room temperature for 45 minutes, with mechanical stirring, 45 ml of hydrogen being absorbed. The reaction mass was filtered, the catalyst washed with 1-2 ml of water, and the combined filtrate and wash water was acidulated with hydrochloric acid (1.19) until its reaction was slightly acid with Congo red. 0.48 gram (96% of the theoretical) of caffeinepropionic acid gradually settled out. A white, finely crystalline substance with an m.p. of 232-233°. It crystallized as minute needles from water, methanol (1:35), and ethyl alcohol (1:40). It is insoluble in benzene or chloroform.

0.3366 g substance: 12.77 ml 0.1 N NaOH. Calculated: 12.65 ml 0.1 N NaOH. 5.387 mg substance: 8.10 mg 0.01 N H_2SO_4. 5.878 mg substance: 8.87 mg 0.01 N H_2SO_4. Found %: N 21.05, 21.12. $C_{11}H_{14}O_4N_4$. Calculated %: N 21.05.

Ethyl ester of β-(caffeine-8)-propionic acid. 2 grams of caffeinepropionic acid was heated for 4 hours with a mixture of 30 ml of absolute ethyl alcohol and 0.5 g of H_2SO_4 (1.84). The alcohol was then driven off, and the residue was treated with ice water, the ester being precipitated with anhydrous $NaHCO_3$ and extracted with chloroform. The ester yield was 1.8 g (81% of the theoretical). White lamellae with an m.p. of 135-136°, very soluble in chloroform, and insoluble in water. The ester crystallizes from alcohol.

5.919 mg substance: 7.97 ml 0.01 N H_2SO_4. 5.876 mg substance: 7.91 ml 0.01 N H_2SO_4. Found %: N 18.85, 18.91. $C_{13}H_{18}O_4N_4$. Calculated %: N 19.05.

Hydrogenating the ethyl ester of β-(caffeine-8)-acrylic acid. A suspension of 0.5 g of the ethyl ester of caffeinacrylic acid in 100 ml of ethyl alcohol was hydrogenated for 40 minutes at room temperature, with mechanical stirring, with 0.5 g of Raney nickel catalyst, 45 ml of hydrogen being absorbed. The catalyst was filtered out, and the alcohol driven off. The ethyl ester of β-(caffeine-8)-propionic acid has an m.p. of 132-133°. The yield was 0.48 g (95% of the theoretical).

Methyl ester of β-(caffeine-8)-propionic acid. 25 grams of caffeinepropionic acid was heated for 4 hours with a mixture of 300 ml of absolute methanol and 5 g of H_2SO_4 (1.84). The ester yield was 23 g (87% of the theoretical). The ester was purified by crystallizing it from 1:10 methanol and ethyl alcohol. Minute white needles with an m.p. of 162-164°.

5.872 mg substance: 8.39 ml 0.01 N H_2SO_4. 5.985 mg substance: 8.60 ml 0.01 N H_2SO_4. Found %: N 20.00, 20.12. $C_{12}H_{16}O_4N_4$. Calculated %: N 20.00.

Sodium β-(caffeine-8)-propionate. An alcoholic solution of NaOH was added to a heated and stirred solution of 5 g of caffeinepropionic acid in 200 ml of absolute alcohol until the reaction with phenolphthalein was slightly alkaline. The solution was stirred for an hour and a half and then allowed to stand overnight. A crystalline precipitate settled out slowly. The solution was heated to boiling and rapidly filtered while hot. The yield was 4 g, or 74% of the theoretical. Driving off the alcohol, dissolving the residue in water, and acidulating the solution yielded 1.1 g of the initial acid. The salt consisted of minute white needles with an m.p. of 280-288° (with decomposition), freely soluble in water and insoluble in organic solvents.

4.675 mg substance: 6.40 ml 0.01 N H_2SO_4. 5.820 mg substance: 8.01 ml 0.01 N H_2SO_4. Found %: N 19.20, 19.28. $C_{11}H_{13}O_4N_4Na$. Calculated %: N 19.44.

(Caffeine-8)-isosuccinic acid. 50 grams of (caffeine-8)-methylenemalonic acid was dissolved in 325 ml of 1N NaOH, and 10 g of a Raney nickel catalyst was added. Hydrogenation lasted 6 hours at room temperature, with mechanical agitation, 3690 ml of hydrogen being absorbed. The reaction mass was filtered, the catalyst washed with water, and the combined filtrate and wash water acidulated with hydrochloric acid (sp. gr. 1.19) until the reaction with Congo red was slightly acid. A coarse crystalline precipitate slowly settled out upon standing. The yield was 48 g (96% of the theoretical). Transparent crystals with an m.p. of 230-232°, freely soluble in alcohol. It crystallized from water (1:30) as colorless, square, lamellae. When a solution of the sodium salt was acidulated, the acid settled out as large rhombic lamellae. Insoluble in benzene, acetone, ethyl acetate, or chloroform.

5.309 mg substance: 6.85 ml 0.01 N H_2SO_4. 5.00 mg substance: 6.40 ml 0.01 N H_2SO_4. Found %: N 18.06, 17.92. $C_{12}H_{14}O_6N_4$. Calculated %: N 18.06.

Diethyl ester of β-(caffeine-8)-isosuccinic acid. 4 grams of β-(caffeine-8)-isosuccinic acid was heated for 4 hours with a mixture of 60 ml of absolute ethyl alcohol and 1 g of H_2SO_4 (1.84). The ester yield

was 3.6 g (76.0 % of the theoretical.). Transparent prisms with an m.p. of 101 - 102°, soluble in the cold in benzene and chloroform. It crystallized from 1:2 alcohol and from 1:80 water. It is insoluble in ether.

7.76 mg substance: 8.43 ml 0.01 N H_2SO_4. 7.43 mg substance: 8.08 ml 0.01 N H_2SO_4.
Found %: N 15.21, 15.21. $C_{16}H_{22}O_6N_4$. Calculated %: N 15.30.

Hydrogenating the diethyl ester of β-(caffeine-8)-methylenemalonic acid. A suspension of 0.5 g of the ester in 150 ml of ethyl alcohol plus 0.5 g of Raney nickel catalyst was hydrogenated for 45 minutes at room temperature, with mechanical stirring, 45 ml of hydrogen being absorbed. The m.p. of the resultant diethyl ester of β-(caffeine-8)-isosuccinic acid was 101-102°. The yield was 0.47 g (94% of the theoretical.).

Condensing 8-monochloromethylcaffeine with sodium malonic ester. A suspension of 0.5 g of finely divided sodium in 30 ml of absolute toluene was stirred while 6.4 g of the malonic ester was added. After the metallic sodium had vanished, the reaction mixture was cooled to 20-40°, and 4.8 g of thoroughly pulverized anhydrous 8-monochloromethylcaffeine was added, after which heating was resumed for 1 hour. The toluene was then driven off in vacuo. The crystallized residue weighed 6 g, with an m.p. of 98-100°. The yield was 82% of the theoretical. The ester was purified by crystallizing it from water. The ester was identical with the diethyl ester of β-(caffeine-8)-isosuccinic acid, synthesized by esterifying the acid and by hydrogenating the ester of (caffeine-8)-methylenemalonic acid.

Decarboxylating β-(caffeine-8)-isosuccinic acid. 10 grams of β-(caffeine-8)-isosuccinic acid was heated to 130° with 45-50 ml of quinoline. The caffeinepropionic acid that crystallized out upon cooling was filtered out and thoroughly washed with dilute HCl and with water. It was purified by dissolving it in a solution of $NaHCO_3$, filtering the solution, and then acidulating the solution of the sodium salt. The yield was 7.85 g (91% of the theoretical).

Saponifying and decarboxylating the diethyl ester of β-(caffeine-8)-isosuccinic acid. 5 grams of the diethyl ester of (caffeine-8)-isosuccinic acid was boiled for 4.5 hours with 50 ml of dilute (1:1) HCl. The hot solution was decolorized with charcoal, filtered, and cooled, after which the chilled solution was neutralized, first with an alkali solution, and then with anhydrous $NaHCO_3$ until its reaction with Congo red was faintly acid. The precipitated caffeinepropionic acid was purified in the usual manner. The yield was 3.5 g (95.5% of the theoretical.)

Preparation of β-(caffeine-8)-propionyl chloride. 2 grams of the anhydrous acid was heated with 15 ml of absolute benzene and 1 g of thionyl chloride* and stirred until all the acid had dissolved at the boiling point of benzene. Upon cooling, yellow crystals with an m.p. of 127-135° adhered to the walls of the flask. The yield was 1.5 g (70% of the theoretical). The benzene mother liquor was processed with 20 ml of 25% aqueous ammonia, yielding 0.35 g of caffeinepropionamide, with an m.p. of 229-232° (see below).

β-(Caffeine-8)-propionamide. a) A mixture of 20 g of caffeinepropionic acid, 150 ml of absolute benzene, and 10 g of thionyl chloride was stirred and heated for 3-4 hours until all the acid had dissolved. The resultant solution of the acid chloride was cooled, the crystallized mass being gradually added to 100 ml of 25% aqueous ammonia, stirred and chilled externally. Stirring was continued for 1.5 to 2 hours after the addition had been completed. The amide was filtered out and crystallized from butyl alcohol. The yield was 16.9 g (85% of the theoretical). Extremely minute white needles with an m.p. of 233-235°, slightly soluble in water and crystallizable from 1:60 ethyl alcohol and from 1:40 butyl alcohol.

4.855 mg substance: 9.07 ml 0.01 N H_2SO_4. 4.833 mg substance: 8.99 ml 0.01 N H_2SO_4.
Found %: N 26.15, 26.04. $C_{11}H_{15}O_3N_5$. Calculated %: N 26.41.

b) 4.5 grams of the methyl ester of caffeine propionic acid was agitated in a stoppered bottle for 24 hours with 60 ml of methanol and 50 ml of 28.5% aqueous ammonia. The amide was then filtered out, washed with water, and dried. M.p. 232-234°; weight 2.4 g (52% of the theoretical). After the mother liquor had been evaporated in vacuo and acidulated, we recovered 1.4 g of caffeine propionic acid, equivalent to 34% of the theoretical.

Dimethylamide of β-(caffeine-8)-propionic acid. 3-4 ml of liquid dimethylamine was poured into a chilled solution of 5 g of unrefined caffeinepropionyl chloride in 50 ml of absolute benzene. The reaction

*) The thionyl chloride was refined by boiling it with sulfur, followed by fractional distillation [7].

mixture was set aside to stand in a stoppered bottle at room temperature. The crystalline dimethylamide with an m.p. of 186-188°, gradually settled out of the transparent solution. The yield was 2.6 g (50% of the theoretical). Snow-white needles with an m.p. of 188-189°, soluble in the cold in chloroform, and crystallizable from 1:1 water, from 1:20 alcohol, from 1:30 ethyl acetate, and from 1:50 benzene.

5.846 mg substance: 10.01 ml 0.01 N H_2SO_4. 6.016 mg substance: 10.42 ml 0.01 N H_2SO_4.
Found %: N 23.97, 24.25. $C_{13}H_{19}O_3N_5$. Calculated %: N 23.88.

Dimethylaminoethyl ester of β-(caffeine-8)-propionic acid (hydrochloride). A cold solution of 3 g of unrefined caffeinepropionyl chloride in benzene was stirred at room temperature while 1.1 g of redistilled dimethylaminoethanol was added. The reaction mass was then stirred for 3 hours at the boiling point of benzene. The reaction mass was cooled, and the precipitated hydrochloride of the dimethylaminoethyl ester of caffeinepropionic acid was filtered out and recrystallized from butyl alcohol. The yield was 2.8 g (71% of the theoretical). Minute white needles with an m.p. of 222-224°, freely soluble in water, insoluble in benzene, crystallizable from ethyl alcohol and butyl alcohol.

7.719 mg substance: 2.955 mg AgCl. 6.759 mg substance: 2.555 mg AgCl.
Found %: Cl 9.47, 9.35. $C_{15}H_{23}O_4N_5 \cdot HCl$. Calculated %: Cl 9.54.

Diethylaminoethyl ester of β-(caffeine-8)-propionic acid (hydrochloride). A cold solution of 3 g of unrefined caffeinepropionyl chloride in benzene was stirred while 1.23 g of redistilled diethylaminoethanol was gradually added. The reaction mass was then stirred for 3.5 hours at the boiling point of benzene. The precipitated hydrochloride of the diethylaminoethyl ester of caffeinepropionic acid was filtered out and crystallized from butyl alcohol. The yield was 1.5 g (38% of the theoretical). Minute white needles with a m.p. of 226-228°, freely soluble in water, insoluble in benzene, and crystallizable from ethyl and butyl alcohol.

6.765 mg substance: 2.439 mg AgCl. 6.603 mg substance: 2.346 mg AgCl.
Found %: Cl 8.92, 8.79. $C_{17}H_{27}O_4N_5 \cdot HCl$. Calculated %: Cl 8.84.

SUMMARY

1. A method has been found for synthesizing caffeine derivatives with aliphatic acid groups containing a three-membered carbon chain at the 8-position from caffeine-8-aldehyde.

2. It has been found that the caffeine derivatives with mono- and dibasic aliphatic acid groups containing a three-membered carbon chain substituted at the 8 position are highly stable, in contrast to the highly unstable 8-caffeinecarboxylic acid and caffeinacetic acids.

3. The following acids have been synthesized: (caffeine-8)-methylenemalonic acid, (caffeine-8)-isosuccinic acid, β-(caffeine-8)-acrylic acid, and β-(caffeine-8)-propionic acid, as well as their methyl and ethyl esters. We have also synthesized the dimethylaminoethyl and diethylaminoethyl esters, and the amide and dimethylamide of β-(caffeine-8)-propionic acid.

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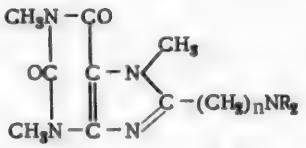
THE 8- SUBSTITUTION DERIVATIVES OF METHYLATED XANTHINES

III. AMINOMETHYL AND AMINOETHYLCAFFEINE AND THEIR ALKYLATED DERIVATIVES

E. S. Golovchinskaya and E. S. Chaman

In our continuation of the research initiated [1] on the synthesis of 8-substitution derivatives of methylated xanthines the problem arose of investigating 8-aminomethylcaffeine, 8-aminoethylcaffeine, and their alkylated derivatives.



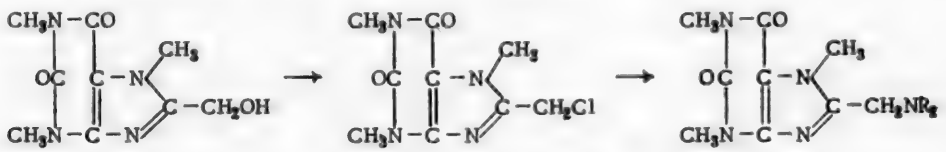
R = H, CH_3, C_2H_5; n = 1 or 2.

The method of synthesizing derivatives of methylated xanthines with amine groups substituted at the 8 position described in the literature [2] is extraordinarily complicated. The method involves the acylation of mono- or dimethylated 2,6-dihydroxy-4,5-diaminopyrimidine with monochloro aliphatic acids instead of the formic acid employed in synthesizing xanthine. The subsequent substitution of an amino or alkylamino group for the halogen and the closure of the imidazole ring by an alkali result in the formation of an xanthine derivative that is methylated in the pyrimidine portion of the molecule, with an aliphatic amine or alkylamine substituted at the 8 position. For example, acylating the diamine of chloracetic acid and substituting an amino group for the chlorine, followed by ring closure and methylating the resultant 8-substitution derivative of xanthine, ought to result in synthesis of aminomethylcaffeine or of its alkylated derivatives.

It is much simpler and cheaper to synthesize these compounds by starting out with 8-monochloromethylcaffeine and substituting amino or alkylamino groups for the active chlorine.

Reacting chloromethylcaffeine with dialkylamines results in the synthesis of dialkylamino derivatives, the yields being almost quantitative, whereas replacing the halogen by an unsubstituted amino group meets with various difficulties. This substitution was carried out in two ways: by synthesizing a phthalylamino derivative and then saponifying its hydrazine hydrate, or by means of a reaction with hexamethylenetetramine. In neither case was the yield of the amine higher than 45% of the theoretical.

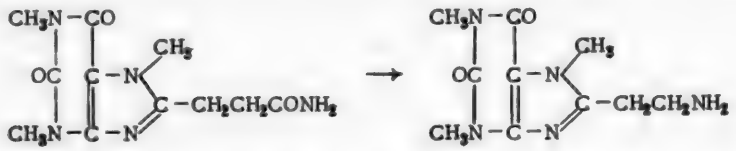
Using the 8-hydroxymethylcaffeine described in one of our previous reports [1] enabled us to eliminate the difficult operation of separating the mixture of chlorinated substances that is invariably produced when 8-methylcaffeine is chlorinated. This mixture is hydrolyzed, and the hydroxymethylcaffeine is isolated from the hydrolyzed substances by utilizing its low solubility in organic solvents. It is again produced, with a high yield of chloromethylcaffeine, when heated with thionyl chloride.



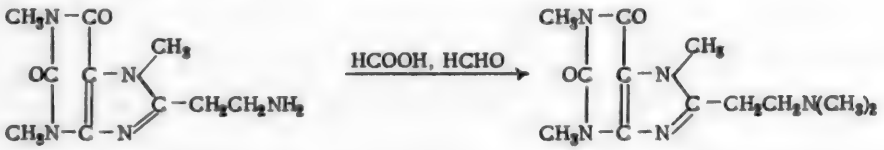
R = H, CH_3, C_2H_5

We prepared phenylaminomethylcaffeine by hydrogenating 8-caffeinylideneaniline [1] with Raney's nickel in alcohol.

With a view to synthesizing 8-aminoethylcaffeine, we investigated the feasibility of converting the β-caffeinepropionamide described in our preceding report [3] into caffeinethylamine in a Hofmann reaction.



This reaction was not impeded by the fact that the initial amide is nearly insoluble in water, since the resultant chloramide or bromamide of caffeinepropionic acid is soluble enough. This made it possible to effect 100 % conversion into an aqueous solution in a comparatively short time when the hypochlorite or hypobromite was reacted with the amide at 2 - 3°. Nor did the high sensitivity of the caffeine ring to alkalies, which is particularly great during heating, interfere with the successful carrying out of the reaction. We were able to convert the bromide into an amine within 5 - 7 minutes, i.e., within an interval in which most of the substance is not broken down by the alkali, notwithstanding the fairly high reaction temperature (60 - 70°). These conditions enable us to secure fairly satisfactory yields of 8-aminoethylcaffeine (44 - 52% of the theoretical, based on the original amide). This caffeine derivative was then successfully converted into dimethylaminoethylcaffeine by methyating a solution of the amine hydrochloride with a mixture of formaldehyde and formic acid.



We are sincerely grateful to O. Yu. Magidson for his assistance in this research.

EXPERIMENTAL

8-Chloromethylcaffeine. 50 grams of 8-hydroxymethylcaffeine was heated on a water bath for 6 hours with 135 ml of thionyl chloride. The resultant transparent solution crystallized during the reaction. After the solution had cooled, the crystals were suction-filtered out, washed with ether, and dried. They weighed 42.8 g; m. p. 215.5 - 216°. The thionyl chloride was driven off from the filtrate, the 10 g of residue being crystallized from ethyl acetate. The crystals weighed 6 g, m.p. 214.5 - 215.5°. The total yield of 8-chloromethylcaffeine was 48.8 g, or 90% of the theoretical.

8-Aminomethylcaffeine. 1) 2.4 grams of potassium phthalimide was added to a boiling solution of 2.4 g of 8-chloromethyl caffeine in 20 ml of chlorotoluene. After 5 hours of heating the chlorotoluene was driven off, its residual traces being driven off with steam. The aqueous suspension was hot-filtered, the resultant 8-phthalylaminomethylcaffeine being crystallized from 40 ml of toluene. It weighed 1.6 g, m.p. 247.5 - 248.5°.

0.1841 g substance; 25.89 ml 0.1 N H_2SO_4. 0.2180 g substance; 30.51 ml 0.1 N H_2SO_4.
Found %: N 19.68, 19.59. $C_{17}H_{15}O_4N_5$. Calculated %: N 19.83.

1.6 grams of the phthalylaminomethylcaffeine was heated on a water bath for 45 minutes with 10 ml of alcohol and 0.6 g of hydrazine hydrate. 10 ml of HCl (1.19) and 10 ml of water were poured over the voluminous, swollen mass, and heating was continued for another 45 minutes. The appearance of the reaction mass changed again, becoming mobile, with a small crystalline precipitate of hydrazine hydrate settling out. The alcohol was driven off in vacuo, the phthalylhydrazide (1.3 g) being suction filtered, and the filtrate alkalinized and repeatedly extracted with chloroform. The extracts were dried with calcined Na_2SO_4 and the chloroform driven off, yielding a residue that weighed 1.5 g. It was crystallized from 150 ml of toluene. Thin pliant needles with an m.p. of 203 - 205°. The yield was 1 g, or 45% of the theoretical.

0.0940 g substance: 20.92 ml 0.1 N H_2SO_4. 0.1065 g substance: 23.72 ml 0.1 N H_2SO_4.
Found %: N 31.15, 31.19. $C_9H_{13}O_2N_5$. Calculated %: N 31.39.

2) A solution of 1.4 g of 8-chloromethylcaffeine and 0.7 g of hexamethyltetramine in 45 ml $CHCl_3$ was heated on a water bath for 2.5 hours. The transparent solution soon turned cloudy as a voluminous white precipitate began to settle out. Upon cooling the reaction mass was filtered, the crystalline salt being air-dried. It weighed 1.3 g. The resultant salt was heated for 20 minutes with 4.8 ml of a 10% solution of HCl in 95% ethyl alcohol, after which the alcohol was driven off. It was reheated with 1.6 ml of the same alcohol, and the mixture of the alcohol with the resultant acetal was again driven off. This last operation was repeated two more times. The flask residue was treated with a bicarbonate solution and repeatedly extracted with chloroform. The extract was dried, and the chloroform driven off. The residue weighed 0.55 g, or 40% of the theoretical. M.p. 201-203°. The m.p. was raised to 203-205° after crystallization from toluene or amyl alcohol. The substance was the same as that produced in the preceding reaction, the mixed melting point being 203-205°.

1 gram of 8-aminomethylcaffeine was dissolved in 3 ml of HCl (1.19), and absolute ethyl alcohol saturated with HCl was added to the solution. The precipitated hydrochloride, with an m.p. of 280-282°, was suction-filtered and twice crystallized from 30 times its weight of 80% ethyl alcohol. Minute white needles, excellently soluble in water, with an m.p. of 284-286°.

6.106 mg substance: 3.345 mg AgCl. 6.894 mg substance: 3.837 mg AgCl.
Found %: Cl 13.55, 13.76. $C_9H_{13}O_2N_5 \cdot HCl$. Calculated %: Cl 13.68.

8-Diethylaminomethylcaffeine. 15 grams of 8-chloromethylcaffeine was boiled on a water bath for 4 hours with 150 ml of diethylamine. The appearance of the reaction mass changed from a thick paste to a mobile transparent solution with transparent crystals suspended in it. The excess diethylamine was driven off, and the residue treated with water. The substance filtered out of the solution of the diethylamine hydrochloride weighed 17.1 g, or 99.7% of the theoretical; m.p. 110°. It crystallized from water in very thin minute needles, and from ether as snow-white, thin, elongated, orthogonal lamellae; m.p. 111.5-113°

5.384 mg substance: 9.53 ml 0.01 N H_2SO_4. 6.231 mg substance: 11.10 ml 0.01 N H_2SO_4.
Found %: N 24.79, 24.96. $C_{13}H_{21}O_2N_5$. Calculated %: N 25.08.

A 15% solution of HCl in absolute ethyl alcohol was added to an ether solution of 8-diethylaminomethylcaffeine until its reaction with Congo red was faintly acid. The hydrochloride settled out as an oil that gradually crystallized. It was recrystallized from 10 times its weight of 96% alcohol. Quadrangular, transparent, white lamellae, m.p. 236 (with decomp.).

6.525 mg substance: 3.130 mg AgCl. 5.025 mg substance: 2.315 mg AgCl.
Found %: Cl 11.44, 11.40. $C_{13}H_{21}O_2N_5 \cdot HCl$. Calculated %: Cl 11.22.

8-Dimethylaminomethylcaffeine. 7.5 grams of chloromethylcaffein was heated to 50-60° for a long time in a sealed tube with 50 ml of dimethylamine, with frequent shaking.

After dissolution was complete, the excess dimethylamine was driven off, the residue dissolved in water, and the base isolated by adding 40% NaOH, the flask being cooled externally. The base separated out as an oil that solidified quickly; then it was suction-filtered out and dissolved in chloroform. The solution was dried over calcined Na_2SO_4, and the chloroform driven off, the residue weighing 7.5 g, or 95.5% of the theoretical. M.p. 124-125°. It crystallized from ether as elongated transparent lamellae. M.p. of the recrystallized substance: 125-126°.

4.402 mg substance: 8.70 ml 0.01 N H_2SO_4. 4.246 mg substance: 8.33 ml 0.01 N H_2SO_4.
Found %: N 27.67, 27.47. $C_{11}H_{17}O_2N_5$. Calculated %: N 27.88.

7 grams of 8-dimethylaminomethylcaffeine was dissolved by gentle heating in 60 ml of ethyl alcohol, and 20 ml of alcohol saturated with HCl was added to make the reaction with Congo red slightly acid. A crystalline precipitate of the hydrochloride settled out. It weighed 7.7 g; m.p. 266-267°. It was recrystallized from 150 ml of 80% alcohol. Needles with an m.p. of 269-271°.

5.271 mg substance: 9.1 ml 0.01 N H_2SO_4. 5.207 mg substance: 8.98 ml 0.01 N H_2SO_4.
8.110 mg substance: 4.070 mg AgCl. 7.285 mg substance: 3.702 mg AgCl.
Found %: N 24.25, 24.14; Cl 12.42, 12.57. $C_{11}H_{17}O_2N_5 \cdot HCl$. Calculated %: N 24.34 Cl 12.34.

8-Phenylaminomethylcaffeine. A suspension of 5 g of 8-caffeinylideneaniline [1] in 200 ml of ethyl alcohol was hydrogenated with 2.5 g of Raney's nickel at room temperature, with mechanical stirring, 440 ml of hydrogen being absorbed within 3.5 hours. The decolorized suspension was heated with 200 ml of alcohol until all the precipitate dissolved, after which the solution was filtered. When the filtrate cooled, 4 g of phenylaminomethylcaffeine, with an m.p. of 190-192°, settled out. Driving off the alcohol and crystallizing the residue yielded another 0.3 g of the amine. The yield totaled 4.3 g, or 86% of the theoretical. The substance dissolves 1:1200 in hot water and 1:70 in alcohol. Minute white needles with an m.p. of 193-194°. It forms readily hydrolyzable salts.

5.723 mg substance: 9.52 ml 0.01 N H_2SO_4. 6.305 mg substance: 10.46 ml 0.01 N H_2SO_4.
Found %: N 23.29, 23.11. $C_{15}H_{17}O_2N_5$. Calculated %: N 23.41.

8-Aminoethylcaffeine. A chilled solution of sodium hypobromite, prepared from 9 g of bromine and 56.3 ml of a 10% NaOH solution, was added drop by drop during the course of an hour, at 35° and with constant stirring, to a suspension of 14 g of caffeinepropionylamide in 100 ml of water. The amide gradually dissolved, the solution being stirred for another 50-60 minutes at 3-5°, after which 60 ml of a 10% NaOH solution was added. Then the reaction mass was heated to 60° for 20-25 minutes and stirred for another 10 minutes at 60-70°. The reaction was considered to be complete when no bromine was liberated from a sample that was acidified with hydrochloric acid. Then the solution was quickly cooled to 20-25° and poured into 100 ml of HCl (1.19), causing the active evolution of CO_2. The acid solution was concentrated in vacuo to a volume of 30-40 ml, the crystallizing sodium chloride filtered out, and the filtrate evaporated in vacuo to dryness. The residue was chilled with ice and treated with a 26% NaOH solution in chloroform the separating aqueous solution being extracted again with chloroform. The chloroform solution was dried over Na_2SO_4 and the chloroform driven off. The residue (6.8 g) was dissolved in 30-35 ml of 96% ethyl alcohol, and an alcoholic solution of HCl was added until the reaction with Congo red was slightly acid. A white crystalline precipitate of the hydrochloride gradually settled out; it was recrystallized from 80% ethyl alcohol. The yield was 6.3 g (44.1% of the theoretical).

8-Aminoethylcaffeine hydrochloride is very soluble in water and crystallizes from 80% ethyl alcohol and from butyl alcohol. White needles with an m.p. of 348-350° (decomp.).

7.158 mg substance: 3.829 mg AgCl. 7.161 mg substance: 3.787 mg AgCl. 5.015 mg substance: 9.13 ml 0.01 N H_2SO_4. 5.095 mg substance: 9.20 ml 0.01 N H_2SO_4. Found %: N 25.49, 25.28; Cl 13.23. 13.08. $C_{10}H_{15}O_2N_5 \cdot HCl$. Calculated %: N 25.59; Cl 12.98.

The base was isolated, as described above, from an aqueous solution of the purified hydrochloride by a 26% alkali solution. The base was refined by recrystallization from toluene.

The 8-aminoethylcaffeine base is freely soluble in water, chloroform, alcohol, ethyl acetate, and acetone, and slightly soluble in benzene. Yellowish needles with an m.p. of 143-144°.

4.397 mg substance: 9.17 ml 0.01 N H_2SO_4. 4.196 mg substance: 8.76 ml 0.01 N H_2SO_4.
Found %: N 29.17, 29.23. $C_{10}H_{15}O_2N_5$. Calculated %: N 29.53.

8-Benzylideneaminoethylcaffeine. 0.5 gram of benzaldehyde was added to a solution of 1 g of 8-aminoethylcaffeine in alcohol. The mixture was heated for 20 minutes, the yellowish needles of the benzylidene base crystallizing out upon cooling. The yield was 0.8 g (61.5% of the theoretical). The substance crystallizes from methanol and ethyl alcohol. It is hydrolyzed when heated with water. White needles with an m.p. of 180-181°.

4.749 mg substance: 7.32 ml 0.01 N H_2SO_4. 4.623 mg substance: 7.14 ml 0.01 N H_2SO_4.
Found %: N 21.58, 21.61. $C_{17}H_{19}O_2N_5$. Calculated %: N 21.54.

8-Dimethylaminoethylcaffeine. A solution of 7.6 g of 8-aminoethylcaffeine hydrochloride in 15 ml of water was added a drop at a time during the course of 40-50 minutes to a methylating mixture consisting of 8 g of a 28.69% solution of formalin and 8 g of 85% formic acid, heated to 95°. After the reaction mass had been stirred for 8 hours at 100-102°, it was chilled with a snow-salt mixture. The amine was isolated by processing with a 26% alkali solution and then quickly extracting with chloroform. The chloroform solution was dried over calcined Na_2SO_4, the chloroform being driven off, and the residue crystallized from diethyl ether. The yield was 5 g, or 68.5% of the theoretical. Minute white needles with an m.p. of 100-102°. Freely soluble in the cold in water, chloroform, alcohol, and benzene and soluble when heated in diethyl ether.

3.891 mg substance: 7.266 ml 0.01 N H_2SO_4. 2.595 mg substance: 4,89 ml 0.01 N H_2SO_4.
Found %: N 26.14, 26.40. $C_{12}H_{19}O_2N_5$. Calculated %: N 26.41.

A solution of HCl in absolute alcohol was added to an ether solution of 8-dimethylaminoethylcaffeine until the reaction with Congo red was slightly acid. The finely crystalline white precipitate of the hydrochloride was recrystallized from 96% alcohol. Minute white needles, freely soluble in water, decomposing at 257°.

5.975 mg substance: 2.829 mg AgCl. 7.136 mg substance: 3.420 mg AgCl.
Found %: Cl 11.71, 11.85. $C_{12}H_{19}O_2N_5 \cdot HCl$. Calculated %: Cl 11.77.

SUMMARY

1. A method is set forth for synthesizing 8-aminomethylcaffeine and its alkylated derivatives from 8-chloromethylcaffeine.

2. The conditions required for converting β-(caffeine-8)-propionamide into 8-aminoethylcaffeine have been determined.

3. The following compounds have been synthesized: 8-aminomethylcaffeine, 8-dimethylaminomethylcaffeine, 8-diethylaminomethylcaffeine, 8-aminoethylcaffeine, 8-dimethylaminoethylcaffeine, and the hydrochlorides of these compounds, as well as 8-phenylaminomethylcaffeine, and 8-benzylideneaminoethylcaffeine.

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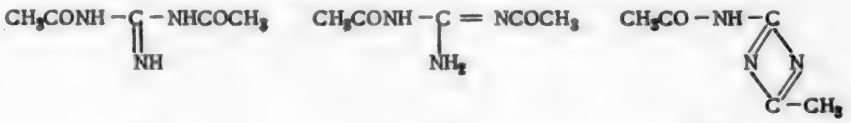
*) See Consultants Bureau English translation, p. 593.

THE TRANSFORMATION OF GUANIDINE DURING ACETYLATION[1)]

A. A. Ryabinin

When Korndorfer acetylated the salts of guanidine [1], he secured compounds that he described as symmetric (I) and asymmetric (II) diacetylguanidines and the anhydride of diacetylguandine (III).



(I) (II) (III)

Although a large number of substituted guanidines has been synthesized by now, no one has succeeded in isolating tautomers resembling (I) and (II). We were, therefore, interested in checking Korndorfer's research. We secured a substance, $C_5H_9O_2N_3$, with an m.p. of 166°, by heating salts of guanidine to 100° with twice their weight of acetic anhydride. The formula for this compound is that for diacetylguanidine as well as for an acetate of the anhydride of monoacetylguanidine like (III), for example. Analysis of the picrate of the $C_5H_9O_2N_3$ substance indicated that it was the monopictrate of diacetylquanidine. Thus, the $C_5H_9O_2N_3$ substance with an m.p. of 166° we had prepared was a diacetylguanidine hitherto unknown in the literature.

When Korndorfer acetylated guanidine carbonate under the same conditions, he secured an acetate of a monoacetyl derivative. This was because he employed recrystallization from water. Our diacetylguanidine was extremely unstable, being totally converted into monoacetylguanidine acetate when heated for a long time in alcohol.

When we heated guanidine acetate of carbonate with five times its weight of acetic anhydride to the boiling point of the solution, we secured two other substances: $C_6H_9ON_5$, with an m.p. of 285°, and $C_8H_{11}O_2N_5$, with an m.p. of 217.5°. These formulas differ by one acetyl group. We noticed that the compound $C_8H_{11}O_2N_5$ was unstable. It loses an acetyl group when recrystallized from 5% acetic acid, being converted into the other synthesized compound, $C_6H_9ON_5$. The converse transformation was effected by boiling with acetic anhydride. The elementary composition of these substances as well as the methods employed in their formation make it probable that their structure is that of acetyl derivatives: 4, 6-diamino-2-methyl-1, 3, 5-triazine (IV).

M. Nencki [2], Diels [3], and Simons and Weaver [4] have observed that 4, 6-diamino-2-methyl-1,3,5-triazine is formed when the acetate or the monoacetyl derivative of quanidine was heated to 190-230°. In our experiments, we found that the reaction proceeded under milder conditions when an excess of acetic anhydride was present.

A. Ostrogovich [5] secured 4, 6-diacetylamino-2-methyl-1, 3, 5-triazine (V) with an m.p. of 212-213° by acetylating 4, 6-diamino-2-methyl-1, 3, 5-triazine, while recrystallizing the compound (V) from ethyl acetate or acetic acid yielded 4-amino-6-acetylamino-2-methyl-1, 3, 5-triazine with an m.p. of 284° (VI). It is obvious that these compounds are the same as those we synthesized.

The slight discrepancy in the melting points of the diacetyl derivative is due to the ease with which this compound is decomposed.

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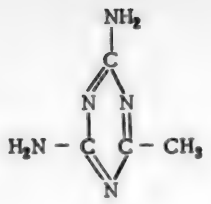
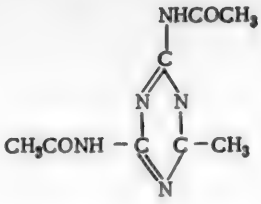
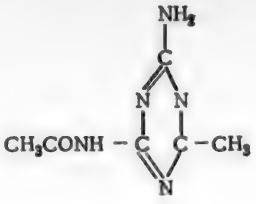
1) The contents of a research paper by Grundmann and Beyer recently published (Ber. 83, 452) are very close to those of the present paper. Where the two papers agree, they reach the same conclusions. The paper of the foregoing authors was submitted to the editors on March 31, 1950, i.e., at practically the same time as the present paper reached the editors of the Journal of General Chemistry of the U.S.S.R.



(IV)



(V)



(VI)

There is no doubt that the anhydride of diacetylguanidine, with an m.p. of 210-212°, and the asymmetric diacetylguanidine, with an m.p. of 271°, described by Korndorfer, are the impure di- and monoacetyl derivatives of 4, 6-diamino-2-methyl-1, 3, 5-triazine. This is shown by a comparison of their melting points and the reciprocal transformations of the substance synthesized by Korndorfer and by us. In Korndorfer's experiments, for example, saponifying the anhydride of diacetylguanidine yielded asymmetrical diacetylguanidine, which was reconverted into the original compound when heated with acetic anhydride. Our conclusion is likewise borne out by the fact that we have been unable to secure any other substances than those described above and diacetylurea, notwithstanding our numerous acetylation experiments conducted under the conditions described by Korndorfer. Korndorfer's symmetric diacetylguanidine, with an m.p. of 152°, which forms no salts, is apparently identical with the diacetylurea. The mistake made by that author lay in his failure to make a nitrogen determination.

EXPERIMENTAL

Preparation of guanidine acetate. 50 grams of guanidine carbonate was dissolved in water, neutralized with acetic acid, and evaporated to dryness in vacuo. The acetate was crystallized from alcohol as prisms with an m.p. of 229° by adding ether (the m.p. is given as 229-230° in the literature [6]).

Preparation and analysis of diacetylguanidine. In one of our runs 5 g of guanidine acetate was heated on a boiling water bath for two hours with 10 g of acetic anhydride (b.p. 137-139°). Two grams of crystals, in the shape of large needles, settled out of the cooled solution. The substance had a melting point of 166° after having been dried at 95°. The melting point did not change after rapid recrystallization from 95% alcohol and drying.

0.1175 g substance: 0.1800 g CO_2; 0.0676 g H_2O. 0.1169 g substance: 0.1778 g CO_2; 0.0687 g H_2O. 0.0731 g substance: 19.10 ml N_2 (22°, 760 mm). Found %: C 41.78, 41.48; H 6.44, 6.57; N 29.44. $C_5H_9O_2N_3$. Calculated %: C 41.93; H 6.34; N 29.37.

Preparation and analysis of diacetylguanidine picrate. 0.3 gram of diacetylguanidine and 0.48 g of picric acid were dissolved in separate portions of methanol. When the two solutions were combined, a finely crystalline picrate, with an m.p. of 163-164°, settled out. Recrystallization from absolute methanol yielded the picrate as large yellow needles with an m.p. of 164-165°.

0.0596 g substance: 12.02 ml N_2 (23°, 764 mm). Found %: N 22.74. $C_5H_9N_3O_2 \cdot C_6H_3N_3O_7$. Calculated %: N 22.59.

Preparation and analysis of monoacetylguanidine acetate. 5 grams of guanidine acetate was heated on a boiling water bath for two hours with 10 g of acetic anhydride. The crystals that settled out as the solution cooled were filtered out and twice recrystallized from 95% alcohol without having been dried. This yielded 2 g of needles with an m.p. of 177-178° (the m.p. given in the literature is 177-178° [1]). The mixed melting point with diacetylguanidine was 150°.

0.1233 g substance: 0.1699 g CO_2, 0.0805 g H_2O. 0.1266 g substance: 0.1730 g CO_2; 0.0804 g H_2O. 0.0708 g substance: 16.30 ml N_2 (22°, 768 mm). Found %: C 37.58, 37.27; H 7.30, 7.10; N 26.22. $C_5H_{11}O_3N_3$. Calculated %: C 37.24; H 6.88; N 26.08.

Preparation of monoacetylguanidine picrate. This salt was prepared as described above; the minute yellow needles melted at 237.5-238.5°.

Preparation and analysis of 4,6-diacetylamino-2-methyl-1, 3, 5-triazine. 1 gram of guanidine acetate was boiled for one hour with five g of acetic anhydride. The crystals that settled out upon cooling were dried

in vacuo over alkali. The substance had a m.p. of 217.5° after double recrystallization from boiling water. 5.3 grams of the same substance was secured from 15 g of guanidine carbonate by a similar procedure.

0.1230 g substance: 0.2077 g CO_2; 0.0590 g H_2O. 0.1118 g substance: 0.1875 g CO_2; 0.0540 g H_2O. 0.0651 g substance: 19.45 ml N_2 (22°, 760 mm). Found %: C 46.05, 45.74; H 5.37, 5.40; N 33.66. $C_8H_{11}O_2N_5$. Calculated %: C 45.69; H 5.28; N 33.34.

Preparation and analysis of 4-amino-6-acetylamino-2-methyl-1, 3, 5-triazine. 5 grams of guanidine acetate was boiled for one hour with 25 g of acetic anhydride. The resulting crystals were recrystallized from boiling water without having been dried. This yielded 1.35 g of crystals with an m.p. of 284°. The m.p. rose to 285° after four recrystallizations from boiling water.

0.1209 g substance; 0.1900 g CO_2; 0.0596 g H_2O. 0.1152 g substance: 0.1819 g CO_2; 0.0580 g H_2O. 0.0410 g substance: 14.98 ml N_2 (22°, 769 mm). Found %: C 42.86, 43.06; H 5.52, 5.63; N 41.67. $C_6H_9ON_5$. Calculated %: C 43.09; H 5.43; N 41.91.

Preparation and analysis of diacetylurea. The mother liquors secured in the preceding experiments after the crystalline substances that settled out of the acetic anhydride had been filtered out were concentrated in vacuo. The resulting crystalline deposits constituted a mixture that fused broadly in the 130-145° range. The deposits were combined and fractionated by recrystallization from alcohol. This yielded, in addition to the substances secured in the previous tests, 2 g of pure diacetylurea, with an m.p. of 154.5-155.5° (the m.p. is given in the literature as 152-153° [6]. The mixed melting point with diacetylguanidine was unsharp, beginning at 124°.

0.1136 g substance: 0.1728 g CO_2; 0.0556 g H_2O. 0.0516 g substance: 8.70 ml N_2 (20°, 770 mm). Found %: C 41.49; H 5.48; N 19.44. $C_5H_8O_3N_2$. Calculated %: C 41.64; H 5.59; N 19.44.

Conversion of diacetylguanidine into monoacetylguanidine acetate. A few grams of diacetylguanidine, with an m.p. of 166°, was recrystallized from 95% alcohol. After the first recrystallization the melting point dropped to 164-165°, while after the second we secured a substance with an m.p. of 178°. The mixed melting point with monoacetylguanidine acetate exhibited no depression.

Conversion of monoacetylguanidine acetate into 4, 6-diacetylamino-2-methyl-1, 3, 5-triazine. One gram of monoacetylguanidine was boiled for one hour with 5 g of acetic anhydride. When the solution cooled, crystals with an m.p. of 214° settled out. The mixed melting point with the pure substance was 216°.

Reciprocal conversions of 4, 6-diacetylamino-2-methyl-1, 3, 5-triazine and 4-amino-6-acetylamino-2-methyl-1, 3, 5-triazine. A few grams of 4, 6-diacetylamino-2-methyl-1, 3, 5-triazine, with an m.p. of 217°, was recrystallized from boiling 5% acetic acid. This yielded crystals with an m.p. of 285°. 0.5 gram of the resulting substance was heated with acetic anhydride. Upon cooling, crystals with an m.p. of 217° settled out.

SUMMARY

1. Diacetylguanidine, with an m.p. of 166°, and its monopicrate, which are unknown in the literature, are described.

2. It has been found that heating guanidine salts with acetic anhydride yields 4, 6-diacetylamino-2-methyl-1, 3, 5-triazine and 4-amino-6-acetylamino-2-methyl-1, 3, 5-triazine.

3. It has been shown that the two diacetyl derivatives of guanidine described in the literature — the symmetric with an m.p. of 152° and the asymmetric with an m.p. of 271° — do not exist. These names were employed erroneously to describe diacetylurea and impure 4, 6-amino-6-acetylamino-2-methyl-1, 3, 5-triazine.

4. It has been shown that the anhydride of diacetylguanidine, with an m.p. of 210-212°, described in the literature does not exist. This name was employed erroneously to describe impure 4, 6-diacetylamino-2-methyl-1, 3, 5-triazine.

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Institute of Botany
U.S.S.R. Academy of Sciences

THE DENDRITIC CRYSTALLIZATION OF VARIOUS SALTS FROM AQUEOUS SOLUTIONS

I. The Formation of Dendritic Crystals of NH_4Cl, KCl, and NaCl, and Their Modification by Various Impurities. page 461.

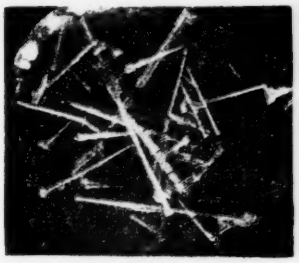

Figure 5.

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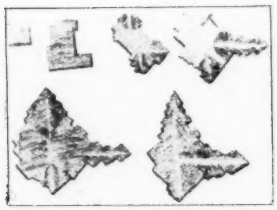

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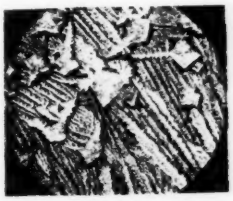

Figure 2.

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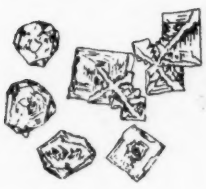

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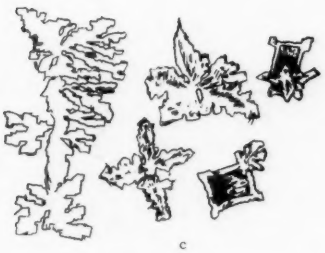

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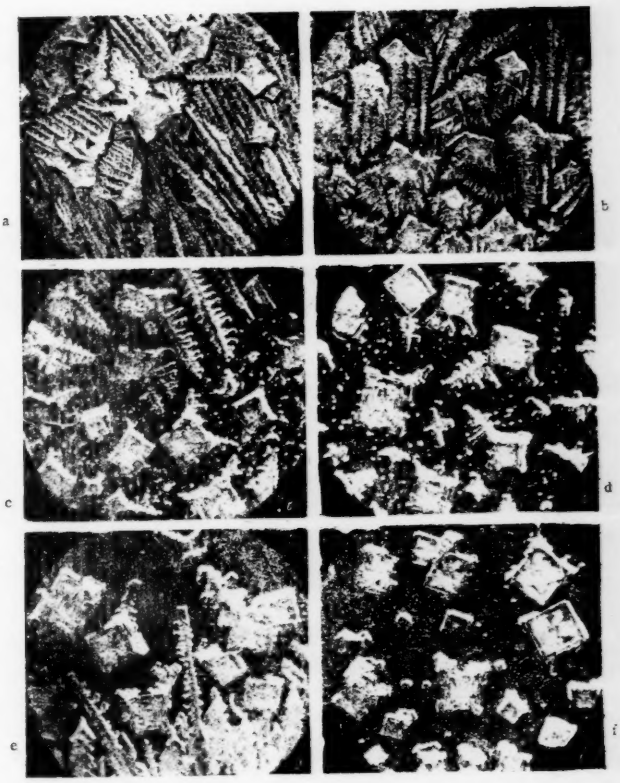

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Figure 6.

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